BOTANY

for Degree Students

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Preface

BOTANY for Degree Students is an enlarged version of the author's *A Class-book of Botany*, eleventh edition, with necessary modifications and considerable additions. The book, as the name implies, is meant to meet the need of students preparing for the three-year or two-year degree examination (pass standard) of Indian Universities. With this end in view an attempt has been made to cover as far as possible the syllabuses for the above courses. The author has tried to present the subject matter in an easily understandable way without sacrificing the essential details and general principles and yet avoiding redundant matter and unnecessary complications. The book, as it stands, is expected to meet adequately the need of the students for whom it is meant.

The book has been profusely illustrated with neat and accurate sketches mostly drawn by the author. In doing so special care has been taken to represent particular features clearly and boldly. This has, however, necessitated in some cases the omission of certain details not required by the topic under discussion. Some photographs by the author, depicting certain special features under natural
have been incorporated in the book. While reading the
advised to refer frequently to the illustrations
topics. The study of plants in

to another

thanks and gratitude the generous and substantial help rendered by some friends during the course of preparation of the manuscript. The author particularly wishes to mention in this connexion the following: Principal R. N. Nirula of Sree Nilkantheswar College, Khandwa, Prof. P. C. Das of Cotton College, Gauhati, Prof. R. K. Sarker of Bangabasi College, Calcutta, Prof. S. Ghose of St Xavier's College, Calcutta, Dr B. Samantarai of Ravenshaw College, Cuttack, and Prof. N. N. Sarkar of Wesleyan College, Bankura, for their valuable suggestions and comments. The author also expresses his deep sense of gratitude to Prof. C. Kakati of the Chemistry Department, Cotton College, Gauhati for his notes on 'The Colloidal System', to Prof A. K. Ghosh of Calcutta University for his notes on 'Palaeobotany', and to Dr D. B. Deb, Systematic Botanist, Botanical Survey of India, Eastern Circle, Shillong, for certain notes on 'Systematic Botany'. The help thus received has materially contributed to the improvement of the book as a whole. The author also takes this opportunity to express his gratitude to Dr (Mrs) K. Roy and other staff-members of the Botany Department, Cotton College, Gauhati, ex-colleagues of the author, who have very kindly offered him all the necessary facilities for work and study in their laboratory and library. But for their helpful co-operation in other respects, too, the progress of work would have been hampered and delayed.

The illustrations, as incorporated in the book, are mostly the author's own drawings and photographs, either from *A Class-book of Botany*, eleventh edition, or drawn afresh; while others, as listed below, have been adapted from the following publications with the permission of the publishers to whom sincere thanks of the author are due. Thus, with the permission of McGraw-Hill Book Company, Inc., FIG. II/11 has been redrawn from *Introduction to Plant Anatomy* by A. J. Eames and L. H. MacDaniels, edition and copyright 1925; FIGS. II/19, II/20 and II/21 redrawn from *Fundamentals of Cytology* by L. W. Sharp, edition and copyright 1943; FIGS. V/13 and V/14 redrawn from *Cryptogamic Botany* by G. M. Smith, edition and copyright 1938; and FIGS. V/44, V/49, V/126, V/154, V/160-1 and VI/16 from *Plant Morphology* by A. W. Haupt, edition and copyright 1953. With the permission of The University of Chicago Press FIGS. VI/14, VI/15, VI/20D, VI/22 and VI/23A-F have been redrawn from *Gymnosperms: Structure and Evolution* by C. J. Chamberlain, edition and copyright 1935.

Suggestions for further improvement of the book will be thankfully received.

Satribari Road
Gauhati, Assam
May, 1963

A. C. D.

Contents

Introduction

1. **Botany.** The science that deals with the study of living objects goes by the general name of **biology** (*bios*, life; *logos*, discourse or science). Since both animals and plants are living, biology includes a study of both. Biology is, therefore, divided into two branches: **botany** (*botane*, herb) which treats of plants, and **zoology** (*zoon*, animal) which treats of animals.

2. **Scope of Botany.** The subject of botany deals with the study of plants from many points of view. This science investigates the internal and external structures of plants, their functions in regard to nutrition, growth, movements and reproduction, their adaptations to the varying conditions of the environment, their distribution in space and time, their life-history, relationship and classification, the laws involved in their evolution from lower and simpler forms to higher and more complex ones, the laws of heredity, the varied uses that plants may be put to, and lastly, the different methods that can be adopted to improve plants for better use by mankind.

3. **Origin and Continuity of Life.** Life itself is mysterious, and its origin still remains shrouded in mystery. It is assumed, however, that many millions of years ago life first came into existence in water as a speck of protoplasm (*protos*, first; *plasma*, form) from inorganic or non-living materials as a result of certain chemical and physical changes in them under adventitious circumstances. Protoplasm is, therefore, the first-formed living substance. It is interesting to note the following facts: protoplasm is not formed afresh and, therefore, no new life comes into being or can be created; protoplasm is, however, continuous from generation to generation through reproduction; and but for evolution life would have still remained in the first-formed, one-celled stage.

4. **Importance of Green Plants.** Green plants are essential for the existence of all kinds of life including even human life. Their importance in this respect lies, *first*, in the fact that they are the only natural agents which are able to purify the atmosphere by absorbing carbon dioxide gas from it and releasing from their body (by the breaking-down of water) an almost equal volume of pure oxygen to it; and *second*, the green plants prepare food such as starch, the chief constituent of rice, wheat, potato, etc., from the raw materials—carbon dioxide obtained from the air, and water and inorganic salts obtained from the soil. Both these functions, viz., purification of the atmos-

phere and manufacture of food are the monopoly of green plants, and are performed by the green corpuscles or chloroplasts of the leaf during the daytime, sunlight being the source of energy. Animals being devoid of chloroplasts have no such power. It is evident, therefore, that animals including human beings are deeply indebted to plants for these basic needs, viz., oxygen for respiration and food for nutrition and energy. In these respects chloroplasts may be said to hold a strategic position so far as the living world is concerned.

5. **Uses of Plants.** The primary necessities of man are threefold: food, clothing and shelter. All these are extensively supplied by the plant kingdom. The most essential need of man is of course food. This food primarily comes from plants in the form of the cereals (rice, wheat, maize, oat, rye and barley), millets (smaller grains), pulses, vegetables, fruits, some of the vegetable oils, etc. For clothing again plants are indispensable sources of fibres, coarse and fine, for the manufacture of garments. Then again shelter from the inclemencies of the weather and protection against natural enemies have been sought after from time immemorial. In this respect the value of wood, bamboo, cane, reed, thatch grass, etc., is inestimable. With advance in knowledge man has tried to tap plants as sources for his comforts and varied uses. Thus a host of other useful products have been obtained from the plant world through his knowledge and the proper application of it. (See part IX Economic Botany.)

6. **Characteristics of Living Objects.** We do not know what life really is. It is something mysterious and we are not in a position to define it. All living objects have, however, certain characteristics by which they can be distinguished from the non-living. These characteristics are as follows:

(1) **Life-cycle.** All living objects follow a definite life-cycle of birth, growth, reproduction, old age and death.

(2) **Cellular Structure.** All living organisms are composed of characteristic types of structural units, called **cells**. A cell is an organized mass of living substance, called **protoplasm**, with a membrane or wall surrounding it. This cellular structure is an exclusive feature of all living organisms.

(3) **Protoplasm.** Life cannot exist without protoplasm. It is the actual living substance in both plants and animals, and it is, as Huxley defined it, the physical basis of life. It performs all the vital functions. Protoplasm is a highly complex mixture of proteins and a variety of other chemical compounds occurring in particular proportions and in particular patterns and interacting in a harmonious and consistent manner. The property we call life depends on the coordinated action of all these substances.

(4) **Respiration.** All living beings—plants and animals—respire continuously day and night, and for the process of respiration they

take in *oxygen gas* from the atmosphere and give out an almost equa volume of *carbon dioxide gas*. Respiration is an *energy-releasing* process, i.e. the energy that is stored up in the food and other material is released by this process and made use of by the protoplasm for it manifold activities.

(5) **Reproduction.** Living beings—plants and animals—possess the power of reproduction, i.e. of giving rise to new young ones like themselves. Non-living objects have no such power. They may mechanically break down into a number of irregular parts; but living object follow certain definite modes of reproduction periodically and give rise to the offspring of the same kind.

(6) **Metabolism.** Metabolism is a phenomenon of life. It include constructive (or anabolic) and destructive (or catabolic) changes tha the protoplasm is constantly undergoing.

(7) **Nutrition.** A living organism requires to be supplied with food. The chemical constituents of foods are much the same in plants as in animals. These are ultimately digested and assimilated by the protoplasm for its own nutrition and growth. A regular supply of food is thus an indispensable factor to the living organism.

(8) **Growth.** All living objects—plants and animals—grow. Non-living bodies may also grow, as does a crystal. But they differ in many respects. The growth of non-living objects is external, while that of living objects is internal.

(9) **Movements.** Movements are commonly regarded as a sign of life. Movements in most plants, however, are restricted, as most plants are fixed to the ground; while most animals move freely. Moving plants and fixed animals are not, however, uncommon among the lower organisms. Movements in plants and animals may be *spontaneous* or *induced*.

(*a*) **Spontaneous movement** is the movement of an organism or of an organ of a plant or an animal *of its own accord*, i.e. without any external influence. This kind of movement is regarded as a characteristic sign of life. Spontaneous movement is evident in animals, and in plants it is exhibited by many algae, e.g. *Euglena*, many desmids and diatoms, *Oscillatoria*, etc. Among the 'flowering' plants the best example of spontaneous movement is exhibited by Indian telegraph plant (see FIG. III/47). Besides, the streaming movements of protoplasm in the cells of many higher plants are distinctly visible under the microscope.

(*b*) **Induced movement or irritability**, on the other hand, is the movement of living organisms or of their organs in response to ex- [illegible] sorter, sundew, Venus' fly-trap, etc. Leaves of many plants again close up in the evening when the light fails and open again in

morning. This is spoken of as 'sleep' movement. Irritability, however, is more pronounced in animals than in plants.

7. **Differences between the Living and the Non-living.** It is very difficult to trace the absolute differences between the living and the non-living. Certain points, however, may be cited by way of general differences between the two. Protoplasm is the physical basis of life; so all objects containing protoplasm are regarded as living. Non-living objects are conspicuous by its absence. Thus the presence or absence of protoplasm makes a fundamental difference between the animate and the inanimate, and the various life-processes carried on by the protoplasm such as respiration, metabolism, nutrition, growth, movements and reproduction are characteristics of the living objects only. Non-living objects, however, may show movements and growth in a certain sense. Thus non-living objects like machines are seen to move when induced by external forces. Very minute particles embedded in a liquid are also seen to vibrate with great rapidity; this vibration is called **Brownian movement** as it was first observed by Robert Brown in 1828 while examining pollen grains under the microscope. Non-living objects like crystals and corals may also grow, but there is difference in the mode of growth between the living and the non-living, as already discussed. All nerves and tissues undergo fatigue on repeated stimulation from which they recover after a period of rest. Non-living objects like metals may also undergo similar fatigue when worked for a prolonged period, and they can be poisoned or stimulated by drugs, as the late Sir J. C. Bose has experimentally proved. Thus no hard and fast line of distinction can be drawn between the living and the non-living.

8. **Distinctions between Plants and Animals.** Higher plants and higher animals are readily distinguished from one another by their possession of definite organs or members, particularly the organs of locomotion in the latter case, for the discharge of definite functions; but difficulty is experienced where the lower *unicellular* plants and animals are concerned. In fact, no hard and fast line of distinction can be drawn between plants and animals. The distinguishing features in general are as follows:

(1) **Growth.** The regions of growth are localized in the case of plants, lying primarily at the extremities—root-apex and stem-apex—and also in the interior, i.e. growth is both apical and intercalary; while in the case of animals growth is not localized to any definite regions, i.e. all parts grow simultaneously. Moreover, in plants growth proceeds until death; while in animals growth ceases long before death.

(2) **Chlorophyll.** Chlorophyll is highly characteristic of plants with the exception of fungi and total parasites. Chlorophyll and plastids are conspicuous by their absence in animal cells.

(3) **Cell-wall.** Both plants and animals are cellular in composition. Each plant cell, however, is surrounded by a distinct but dead wall, called the *cell-wall.* The cell-wall is almost universally present in all plants and is the most conspicuous part of the cell. The cell-wall, however, is always absent from an animal cell.

(4) **Cellulose.** The cell-wall of the plant cell is made up of a chemical substance, called *cellulose*; pure cellulose, however, is not found in fungi. But it is altogether absent from the animal body.

(5) **Food.** Green plants absorb raw food materials from outside—water and inorganic salts from the soil and carbon dioxide from the air—and prepare organic food substances out of them, primarily in the leaf, with the help of chlorophyll in the presence of sunlight. Animals being devoid of chlorophyll have no power of manufacturing their own food. They have solely to depend on plants for this primary need. It is also to be noted that plants take in food in solution only, whereas animals can ingest solid food.

(6) **Utilization of Carbon dioxide.** Plants possess the power of utilizing the carbon dioxide of the atmosphere. It is only the green cells that have got this power. Thus during the daytime the green cells of the leaf absorb a volume of carbon dioxide from the surrounding air, manufacture sugar, starch, etc., out of this carbon dioxide and water, and give out an almost equal volume of oxygen by the break-down of the water, H_2O (and not carbon dioxide, CO_2). Animals do not possess this power of utilizing the carbon dioxide or of manufacturing food.

(7) **Movements.** Plants grow fixed to the ground or attached to some support, and as such they cannot bodily move from one place to another, except some lower types of plants; while animals move freely in search of food and shelter, and movements when attached [illegible]

[illegible] organs, etc., have reached a stage of perfection in animals for efficient functioning, while in plants the corresponding organs are simple in construction or even altogether absent.

9. Divisions of the Plant Kingdom. There are two main divisions of the plant kingdom, viz., cryptogams (Gr. [illegible]

[illegible] bear flowers and seeds; so cryptogams may be regarded as 'flowerless' or 'seedless' plants, and phanerogams as 'flowering' or 'seed-bearing' plants. Main divisions are:

A. CRYPTOGAMS

(ii) Chlorophyceae or green algae, e.g. *Spirogyra*; (iii) Phaeophyceae or brown algae, e g *Fucus*; (iv) Rhodophyceae or red algae, e.g. *Polysiphonia*. (*b*) Fungi: (i) Myxomycetes or slime fungi; (ii) Phycomycetes or alga-like fungi, e.g. *Mucor*; (iii) Ascomycetes or sac-fungi, e g. *Peziza*; (iv) Basidiomycetes or club-fungi, e g. *Agaricus*; (v) Fungi Imperfecti, e g. *Helminthosporium*. (*c*) Bacteria. (*d*) Lichens (associations of algae and fungi), e g. *Usnea*.

2. Bryophyta. (*a*) Hepaticae or liverworts, e.g. *Riccia*, *Marchantia*, *Porella*, etc. (*b*) Anthocerotae or horned liverwort, e g. *Anthoceros*. (*c*) Musci or mosses: (i) bog mosses, e g *Sphagnum*; (ii) true mosses, e.g. *Funaria*, *Polytrichum*, *Barbula*, etc.

3. Pteridophyta. (*a*) Lycopods, e g *Lycopodium* and *Selaginella*. (*b*) Horsetails, e g *Equisetum*. (*c*) True ferns, e g *Pteris*, *Adiantum*, *Polypodium*, *Dryopteris*, etc. (*d*) Water ferns, e g *Marsilea*, *Salvinia*, *Azolla*, etc.

B. PHANEROGAMS OR SPERMATOPHYTES

1. Gymnosperms, e g. cycads, conifers, *Gnetum*, etc.

2. Angiosperms—dicotyledons and monocotyledons.

Dicotyledons and Monocotyledons. Angiosperms have been divided into two big classes: dicotyledons (*di*, two) and monocotyledons (*monos*, single), primarily on the basis of the number of cotyledons (first introduced by John Ray of Cambridge in 1686 and later followed by others). Other morphological distinctions are: in dicotyledons the primary root persists and gives rise to the tap root, while in monocotyledons the primary root soon perishes and is replaced by a cluster of fibrous roots; as a rule the venation of the leaf is reticulate (net-like) in dicotyledons, while it is parallel in monocotyledons (with but few exceptions in both); and dicotyledonous flower has commonly a pentamerous symmetry, while monocotyledonous flower a trimerous symmetry (see also p. 576).

10. Number of Species on Record

1	Algae	20,000
2	Fungi	73,500
3	Bacteria	1,500
4	Lichens	15,000
5	Bryophyta	23,525
	(a) Liverworts (8,550)	
	(b) Mosses (14,975)	
6	Pteridophyta (ferns & allies)	10,000
7	Gymnosperms	700
8	Angiosperms	199,000
	(a) Dicotyledons (159,000)	
	(b) Monocotyledons (40,000)	
	TOTAL	343,225 species

11. Branches of Botany. Botany, like every other science, may be

studied from [illegible]
botany deals [illegible]
and applied [illegible]
subject as a [illegible]

(1) **Morphology** [illegible]
deals with the stud[illegible]
such as roots, stem[illegible]
external structures [illegible]
morphology, and th[illegible]
The latter may be histology or anatomy.

(2) **Histology** (*histos*, tissue). The study of the detailed structure of tissues making up a particular organ is called **histology**. The study of gross internal structure of a plant organ, as seen in a section, is called **anatomy** (*ana*, asunder; *temnein*, to cut). **Cytology** (*kytos*, cell) dealing with the cell-structure with special reference to the behaviour of the nucleus is a newly established branch of histology.

(3) **Physiology** (*physis*, nature of life). This deals with the various functions that the plants perform. Functions may be *vital* or *mechanical*; vital functions are performed by the living matter, i.e. the protoplasm, and the mechanical functions by certain dead tissues without the intervention of the protoplasm; as, for example, bark and cork protect the plant body, and certain hard tissues strengthen it. It is to be noted that structure and function are correlated, i.e. a particular structure develops in response to a particular function.

(4) **Ecology** (*oikos*, house). This deals with the relationship that exists between an individual plant or a plant community and its surroundings.

(5) **Plant Geography.** This deals with the distribution of plants over the surface of the earth and the factors responsible for such distribution.

(6) **Taxonomy or Systematic Botany.** This deals with the description and identification of plants, and their classification into various natural groups according to the resemblances and differences in their morphological characteristics.

(7) **Palaeobotany** (*palaios*, ancient). This deals with the ancient forms of plants preserved in the form of fossils in the earth's strata in past geological ages.

(8) **Applied or Economic Botany.** This deals with the utilization of plants and plant products for the well-being of mankind, and the various scientific methods employed for their improvement. (See part IX.) It has also several branches: (*a*) **agriculture** dealing with the cultivation of field crops for food and industry; (*b*) **horticulture** dealing with the cultivation of garden plants for flowers and fruits; (*c*) **plant pathology** dealing with the diagnosis, cure and prevention of plant diseases; (*d*) **pharmocognosy** dealing with the study of medicinal

plants with special reference to preparation and preservation of drugs; (*e*) **forestry** dealing with the study of forest plants for timber and other forest products; and (*f*) **plant breeding** dealing with the cross-breeding of plants evolving newer and more improved types with desired characteristics.

12. Parts of an Angiospermic Plant (FIG. 1). Parts of the plant body mainly concerned with the nutrition and growth are called *vegetative parts*, and they comprise the root system and the shoot system (partly). The root system with its differentiated parts performs two

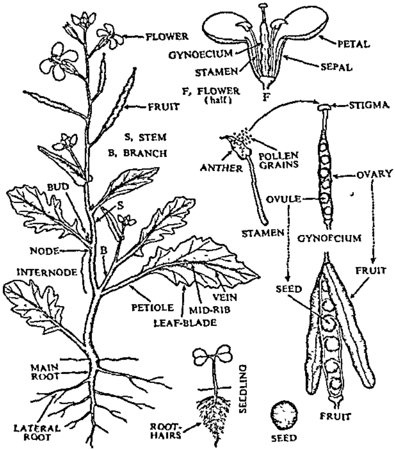


FIG. 1. Parts of an angiospermic plant (mustard plant).

primary functions: fixation and absorption. The shoot system on the other hand may be vegetative or reproductive. The vegetative shoot consisting of main stem, branches and leaves has mainly three functions: support, conduction, and food manufacture (primarily by leaves). The reproductive shoot is the flower with its differentiated organs, and is essentially concerned with the reproduction of the plant.

13. A Short History of Botany. Botany as a subject originally developed out of practice and study of agriculture and medicine in prehistoric times. It was from the 16th century that several attempts were made to systematize the knowledge of the plant kingdom in the shape of classification on scientific lines. From the 18th century classification began to take a definite shape. The 19th century was specially remarkable for the development of the science of Botany in its many branches.

Ancient History. From the records available, meagre though they are, it is known that early civilized men, especially the Assyrians and the Egyptians, as long ago as 5000-3400 B.C., possibly earlier, were acquainted with the uses of certain plants, particularly those with agricultural and medicinal values. They used to cultivate wheat, barley, etc., and grow roses, grapes, pomegranates, dates, figs, etc., and also certain medicinal plants. They also knew the art of pollinating date-palms. **Herodotus**, a Greek historian who travelled to Egypt about 465 B.C., gave a good account of Egyptian agriculture. It is also known that the Chinese as early as 2500 B C. or even earlier used to grow rice, tea, oranges and some medicinal plants. In Greece about 340 B.C. a considerable advance was made in the study of plants, particularly by **Theophrastus** (372-287 B.C.), a disciple of Aristotle (384-322 B.C.). In his book *History of Plants* Theophrastus described about 500 plants of food and medicinal value and other economic uses, with their morphological characteristics, particularly the habit—herbs, shrubs and trees, and annuals, biennials, and perennials. Mention may also be made of **Dioscorides**, a Cilician Greek, and **Pliny**, a meritorious Roman writer, both of 1st century A D The former, a learned physician, described about 600 plants in his *Materia Medica*, while the latter had to his credit *Natural History* complete in 37 volumes. A period of great upheavals—religious, political and social—followed and there was a definite setback in the pursuit of scientific knowledge. 'So far as ancient India is concerned there is mention of SOMA in *Rig Veda* which is the oldest book in the library of man (early half of the third millennium B.C.). The Vedic Aryans were acquainted with about 100 medicinal plants (latter half of the second millennium B.C.). The works of Charaka and Sushruta (last quarter of the first century A.D.) show that Indo-Aryans were acquainted with several medicinal plants. Sushruta mentions about 700 medicinal plants. The rise of Buddhism gave an impetus to the study of medicine in ancient India. The edict of Asoka provided for the establishment of hospitals at all principal towns and cities of India.' (See *Indian Medicinal Plants* by Kirtikar and Basu.) Agricultural practices were also fairly advanced in India during 3,500-2,000 B C.

16th Century. The Renaissance began from this century; medical botany still dominated. **Brunfels** *(1464-1534), a German botanist, wrote his book on medicinal plants in three volumes in 1530.* His work was a link between ancient and modern botany. **Fuchs** (1501-66), a German medical botanist, wrote his *Historia of Plants* in 1542. **Turner** (1515-68), an English physician and botanist, wrote his *A New Herbal* in three volumes in 1551, 1562 and 1568. He was regarded as the father of English botany at that time. **Caesalpino** (1519-1603), an Italian botanist and medical man, wrote his *De Plantis* in 1583 describing about 1,520 plants. In 1596 **Kaspar Bauhin** (1560-1624), an Italian botanist, described about 2,700 plants.

17th Century. In 1620 and 1623 **Bauhin** published his life-long work in the form of two books containing 6,000 species. He introduced binomial names for several

PART I *Morphology*

Chapter 1 THE ROOT

Tap Root System. The primary root and its branches form the tap root system of the plant. The primary or tap root normally grows vertically downwards to a shorter or longer depth, while the branched roots (secondary, tertiary, etc.) grow obliquely downwards, or in many cases spread horizontally outwards. The primary root may be sparingly or profusely branched according to the need of the plant. The tap root system is normally meant to absorb water and mineral salts from the soil, to conduct them upwards to the stem and to give proper anchorage to the plant, but in order to perform some specialized functions it becomes modified into distinct shapes.

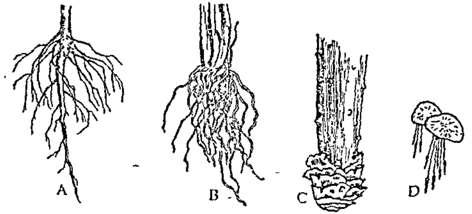


FIG. 2. *A*, tap and lateral roots in a dicotyledon; *B*, fibrous roots in a monocotyledon; *C*, multiple root-cap in screwpine; *D*, root-pocket in duckweed.

Regions of the Root (FIG. 3). The following regions may be distinguished in a root from the apex upwards. There is of course no line of demarcation between one region and another, and each tends to merge into the next.

(1) **Root-cap.** Each root is covered over at the apex by a sort of cap or thimble known as the root-cap which protects the tender apex of the root as it makes its way through the soil. Due to the impact of the hard soil particles the outer part of the root-cap wears away and newer cells formed by the underlying growing tissue are added to it. The root-cap is, however, usually absent in the aquatic plant.

(2) **Region of Cell-division.** This is the growing apex of the root lying within and a little beyond the root-cap and extends to a length of one to a few millimetres. The cells of this region are very small and thin-walled, and contain a dense mass of protoplasm. The characteristic

feature of this region is that the cells undergo repeated divisions, and hence this region is otherwise called the **meristematic region** (*meristos*, divided). Some of the newly formed cells contribute to the formation of the root-cap and others to the next upper region.

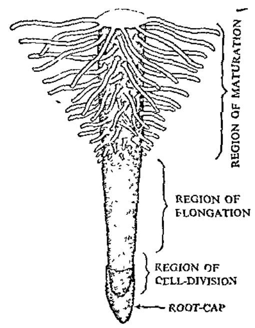


FIG. 3. Regions of the root.

(3) **Region of Elongation.** This lies above the meristematic region and extends to a length of a few millimetres (1 to 5 mm. or a little more). The cells of this region undergo rapid elongation and enlargement, and are responsible for growth in length of the root.

(4) **Region of Maturation.** This region lies above the region of elongation and extends upwards. Externally, often extending to a length of a few millimetres and sometimes a few centimetres, this region produces a cluster of very fine and delicate thread-like structures known as the **root-hairs.** These hairs are essentially meant to absorb water and mineral salts from the soil. Internally, the cells of this region are seen to undergo maturation and differentiation into various kinds of primary tissues. Higher up it gradually merges into the region of secondary tissues. Above the root-hair region lateral roots are produced in *acropetal* succession.

Characteristics of the Root. There are certain distinctive characters of the root by which it can be distinguished from the stem. These are as follows:

(1) The root is the descending portion of the axis of the plant, and is not normally green in colour.

(2) The root does not commonly bear **buds** except in wood-apple (*Aegle*), *Trichosanthes* (B. PATAL; H. PARWAL), Indian redwood (*Dalbergia*), sweet potato, lemon and ipecac. Such plants are sometimes propagated by root-cuttings, e.g. ipecac.

(3) The root ends in and is protected by a cap- or thimble-like structure, known as the **root-cap** (FIG. 3); while the stem ends in a bud. A distinct multiple root-cap is seen in the aerial root of screwpine (FIG. 2C).

In water plants like duckweed (*Lemna*), water lettuce (*Pistia*), water hyacinth,

etc., a loose sheath which comes off easily is distinctly seen at the apex of each root. This is an anomalous root-cap, called the root-pocket (FIG. 2D).

(4) The root bears **unicellular hairs** (FIG. 4B); while the stem or the shoot bears mostly **multicellular hairs** (FIG. 4C). Root-hairs occur in a

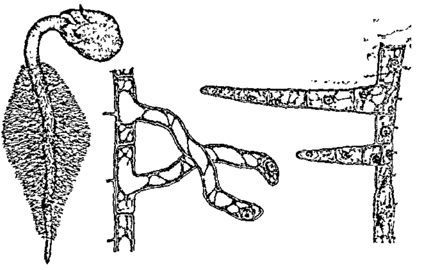


FIG. 4. *A*, root-hairs in mustard seedling; *B*, two root-hairs (magnified)—unicellular; *C*, two shoot-hairs (magnified)—multicellular.

cluster in the tender part of the root a little behind the apex. Shoot-hairs, on the other hand, are of various kinds and they remain scattered all over the surface of the shoot. Root-hairs absorb water and mineral salts from the soil, while shoot-hairs prevent evaporation of water from the surface of the plant body and afford protection.

(5) Lateral roots always develop from an inner layer (pericycle; see FIG. II/63); so they are said to be **endogenous** (*endo*, inner; *gen*, producing). Branches, on the other hand, develop from a few outer layers; so they are said to be **exogenous** (*exo*, outer).

(6) **Nodes** and **internodes** are always present in the stem, although they may not often be quite distinct; but in the root these are absent.

Adventitious Root System. Roots that grow from any part of the plant body other than the radicle are called **adventitious roots**. They may develop from the base of the stem replacing the primary root or in addition to it, or from any node or internode of the stem or the branch, or even from the leaf under special circumstances. Adventitious roots are of various kinds and have diverse functions—normal and specialized. Those with normal functions may be of the following types:

(1) **Fibrous Roots** (FIG. 2B). Fibrous roots of monocotyledons are all adventitious roots. They may be given off in clusters from the

base of the stem, as in onion, tuberose, etc., or from the nodes and sometimes internodes of branches creeping along the ground, as in many grasses, or from the lower nodes of the stem, as in maize, sugarcane, bamboo, etc.

(2) **Foliar Roots** (FIG. 5). Foliar roots are those that come directly out of the leaf, mainly from the petiole or the vein. Such roots may

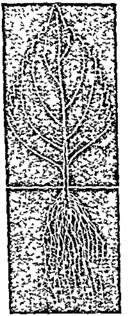


FIG. 5. Foliar (adventitious) roots in *Pogostemon*.

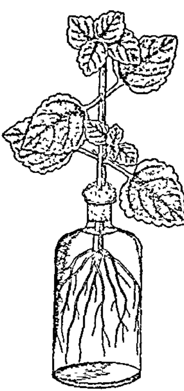


FIG. 6. Adventitious roots in *Coleus*.

sometimes arise spontaneously, or more commonly as a result of injury (e.g. when incised), or they may be induced to grow by the application of certain chemicals, called *hormones*, which are growth-promoting substances. Thus *Pogostemon* leaf when treated with a synthetic hormone, e.g. indole-butyric acid, is seen to produce a cluster of roots from the petiole. Such roots are not common in nature but can be induced to grow by the above treatment.

(3) **Adventitious roots** are also given off by many plants from their nodes and sometimes from the internodes as they creep on the ground, as in Indian pennywort (see FIG. III/55), wood-sorrel (see FIG. 31), etc. Such roots are also produced in many cases from branch-cuttings when these are put into the soil, as in rose, sugarcane, China rose, marigold, tapioca, etc., or kept partially immersed in water in a bottle, as in garden croton, *Coleus* (FIG. 6), etc. Adventi-

tious roots also grow from foliar buds developing on leaves, as in sprout leaf plant (*Bryophyllum pinnatum*; B. PATHUR-KUCHI; H. ZAKHM-I-HAYAT—see FIG. 15B) and elephant ear plant (*Begonia*—see FIG. 15C).

Modified Roots

A. TAP ROOT MODIFIED (for storage of food)

(1) **Fusiform Root** (FIG. 7A). When the root (hypocotyl) is swollen in the middle and gradually tapering towards the apex and the base, being more or less spindle-shaped in appearance, it is said to be fusiform, e.g. radish. In radish it is really the hypocotyl and the base

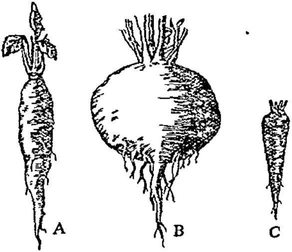


FIG. 7.
Modified Roots.
A, fusiform root of radish;
B, napiform root of turnip;
C, conical root of carrot.

of the stem that swell; only the tapering end is the root proper. (2) **Napiform Root** (FIG. 7B). When the root is considerably swollen at the upper part (usually the hypocotyl), becoming almost spherical, and sharply tapering at the lower part, it is said to be napiform, e.g. turnip and beet. In turnip it is the hypocotyl that swells and becomes spherical; while in beet the hypocotyl and the root together become swollen. (3) **Conical Root** (FIG. 7C). When the root is broad at the base and gradually tapers towards the apex like a cone, it is said to be conical, e.g. carrot. In carrot it is the root proper that swells. (4) **Tuberous or Tubercular Root.** When the root is thick and fleshy but does not take a definite shape, it is said to be tuberous or tubercular, as in four o'clock plant (*Mirabilis*).

B. BRANCHED ROOT MODIFIED (for respiration)

(5) **Pneumatophores.** Many plants growing in marshy places and salt lakes, occasionally inundated by tides, as in the Sundarbans, develop

special kinds of roots, called respiratory roots or pneumatophores (FIG. 8), for the purpose of respiration. Such roots grow from the

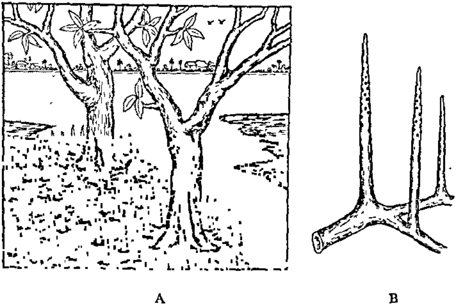


FIG. 8. Pneumatophores. *A*, two plants with pneumatophores; *B*, pneumatophores growing vertically upwards from an underground root.

underground roots of the plant but rise vertically upwards and come out of the water like so many conical spikes. They often occur in large numbers around the tree trunk. Each such root is provided towards the upper end with numerous pores or respiratory spaces through which air is taken in for respiration. Examples are seen in *Rhizophora*, *Heritiera* (B. SUNDRI), etc.

C. *ADVENTITIOUS ROOTS MODIFIED*

(*a*) *For Storage of Food.* (1) **Tuberous or Tubercular Root** (FIG. 9A). This is a swollen root without any definite shape, as in sweet potato (*Batatas*). Tuberous roots, whether tap or adventitious, are produced singly and not in clusters. (2) **Fasciculated Roots** (FIG. 9B). When several tubercular roots occur in a cluster or fascicle at the base of the stem, they are said to be fasciculated, as in *Dahlia*, *Ruellia* and *Asparagus* (B. SATAMULI; H. SATAWAR). (3) **Nodulose Root** (FIG. 9C). When the slender root becomes suddenly swollen near the apex, it is said to be nodulose, as in mango ginger (*Curcuma amada*) and arrowroot (*Maranta*). (4) **Moniliform or Beaded Root** (FIG. 10A). When there are some swellings in the root at frequent intervals, it is said to be moniliform or beaded, as in *Portulaca*, Indian spinach (*Basella*), *Momordica*, wild vine (*Vitis trifolia*) and some grasses. (5) **Annulated Root** (FIG. 10B). When the root has a series of ring-like swellings

on its body, it is said to be annulated, as in ipecac (a medicinal plant).

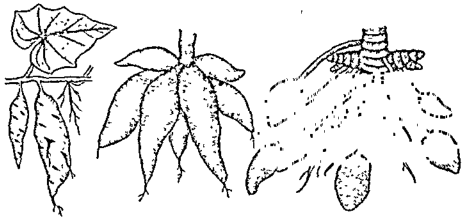


FIG. 9. Adventitious Roots. *A*, tuberous roots of sweet potato; *B*, fasciculated roots of *Dahlia*; *C*, nodulose roots of mango ginger.

(*b*) *For Mechanical Support.* (6) **Prop or Stilt Roots** (FIG. 11). In plants like banyan, India-rubber plant, screwpine, *Rhizophora*, etc., a number of roots are produced from the main stem and often from the branches. These roots grow vertically or obliquely downwards and penetrate into the soil. Gradually they get stouter and act as pillars supporting the main stem and the branches or the plant as a whole. Such roots are known as prop or stilt roots. The big banyan tree in the Indian Botanic Garden near Calcutta has produced over 900 such roots from its branches. Its age is about 200 years, and the circumference of the crown is well over 360 metres. (7) **Climbing Roots** (FIG. 12A). Plants like betel (*Piper betle*), long pepper (*P.* [illegible] gum) black [illegible]

[illegible] the latter [illegible] to ensure a foothold on neighbouring objects.

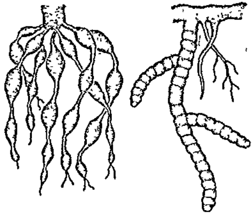


FIG. 10. Adventitious Roots (*contd.*). *A*, moniliform roots of *Momordica*; *B*, annulated roots of ipecac.

(*c*) *For Vital Functions.* (8) **Sucking Roots or Haustoria** (see FIG. [illegible]

22A), mistletoe (*Viscum*; see FIG. 23) and *Loranthus*. (9) **Respiratory Roots** (FIG. 12B). In *Jussiaea* (B. KESSRA), an aquatic plant, the floating branches develop adventitious roots which are soft, light, spongy and colourless. They usually develop above the level of water and serve to store up air. Thus they facilitate respiration. (10) **Epiphytic Roots** (FIG. 13). There are certain plants, commonly the orchids, which grow perched on branches of trees. Such plants are known as *epiphytes* (*epi*, upon; *phyta*, plants). They never suck the supporting plant as do the parasites. So instead of sucking roots they develop special kinds of aerial roots which hang freely in the air. Each hanging root is surrounded by a spongy tissue, called velamen (see FIG. 25). With the help of this velamen the hanging root absorbs moisture from the surrounding air. *Vanda* (B. & H. RASNA), an epiphytic orchid, is a fairly common example. (11) **Assimilatory Roots.** Branches of *Tinospora* (B. GULANCHA; H. GURCHA) climbing on neighbouring trees produce long, slender, hanging roots which develop chlorophyll and turn green in colour. These green roots are the assimilatory roots. The submerged roots of water chestnut (*Trapa*; FIG. 14), usually formed in pairs from the nodes, are green in colour and perform carbon-assimilation. The hanging roots of epiphytic orchids also often turn green in colour and act as assimilatory roots.

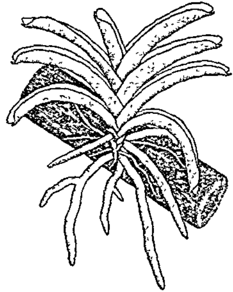


FIG. 13. Epiphytic roots of *Vanda* (an orchid).

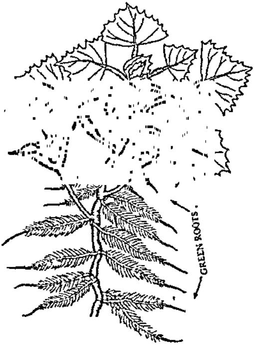


FIG. 14. *Assimilatory (green) roots of Trapa.*

Functions and Adaptations of the Root. The root performs manifold functions—*mechanical* such as fixation, and *physiological* such as absorption, conduction and storage. These are the normal functions of the root. Roots also perform specialized functions and they adapt themselves accordingly. All these functions and adaptations have been discussed in detail in connexion with the modified roots.

Chapter 2 THE STEM

Characteristics of the Stem. The stem is the ascending portion of the axis of the plant, developing directly from the plumule, and bears leaves, branches and flowers. When young, it is normally green in colour. The growing apex is covered over and protected by a number of tiny leaves which arch over it (see FIG. 15A). The stem often bears multicellular hairs of different kinds; it branches exogenously; and it is provided with nodes and internodes which may not be distinct in all cases. Leaves and branches normally develop from the nodes. When the stem or the branch ends in a vegetative bud it continues to grow upwards or sideways. If, however, it ends in a floral bud the growth ceases.

Forms of Stems. There is a variety of stem structures adapted to perform diverse functions. They may be aerial or underground. Aerial stems may be erect, rigid and strong, holding themselves in an upright position; while there are some too weak to support themselves in such a position. They either trail along the ground or climb neighbouring plants or objects. Some stems remain permanently underground and from there periodically give off aerial shoots under favourable conditions; such stems are meant for food storage and perennation (see pp. 20-3).

(1) **Erect or Strong Stems.** The unbranched, erect, cylindrical and stout stem, marked with scars of fallen leaves, is called **caudex**, as in palms. The jointed stem with solid nodes and hollow internodes is called **culm**, as in bamboo. Some herbaceous plants, particularly monocotyledons, have no aerial stem. The underground stem in them produces an erect unbranched aerial shoot bearing either a single flower or a cluster of flowers; such a flowering shoot is called **scape**, as in tuberose, onion, aroids, banana, etc.

(2) **Weak Stems.** A weak stem trailing on the ground without rooting at the nodes is commonly known as (*a*) **trailing**; a trailing stem lying prostrate on the ground is said to be **prostrate or procumbent**, e.g. *Oxalis* and *Evolvulus* (H. SHYAMAKRANTA). When the stem

after trailing on the ground for some distance tends to rise at the apex, it is known as decumbent, e.g. *Tridax* (see FIG. VII/36). When the stem is much branched and the branches spread out on the ground in all directions, it is said to be diffuse, as in hogweed (*Boerhaavia*). A weak stem creeping on the ground and rooting at the nodes is said to be (*b*) creeping; a creeping stem may be a runner, stolon, offset or sucker according to its varied nature (see FIGS. 31-4). When the weak stem attaches itself to any neighbouring object by means of some special devices and climbs it, the stem is said to be (*c*) climbing, e.g. pea, passion-flower, gourd, vine, etc. (see pp. 13-16).

Nodes and Internodes. The place on the stem or branch where one or more leaves arise is known as the node, and the space between two successive nodes is called the internode. Sometimes nodes and internodes are very conspicuous, as in bamboos and grasses; in others they are not always distinct.

The Bud

A bud is a young undeveloped shoot consisting of a short stem and a number of tender leaves arching over the growing apex. In the bud the internodes have not yet developed and thus the leaves remain crowded together forming a compact structure. The lower leaves of the bud are older and larger than those higher up. A cabbage cut longitudinally gives a good idea of a bud—the development of the leaves in *acropetal* succession and the condensed shoot with the growing apex. The normal position of a bud is at the apex of the stem or the branch and in the axil of a leaf. The bud, in the former case, is known as the terminal or apical bud, and in the latter as the axillary bud. Sometimes some extra buds develop by the side of the axillary bud; these are known as the accessory buds. Sometimes buds appear at various other parts of a plant such as the root (radical buds), as in sweet potato, or the leaf (foliar buds), as in sprout leaf plant (*Bryophyllum*; FIG. 15B), elephant ear plant (*Begonia*; FIG. 15C), *Scilla*, walking fern (*Adiantum*; see FIG. III/54), *Kalanchoe* (see FIG. III/57), and water lily (*Nymphaea*), or at different positions of the stem and the branches (cauline buds). Such buds are known as adventitious because of their abnormal position.

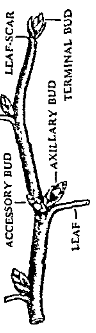
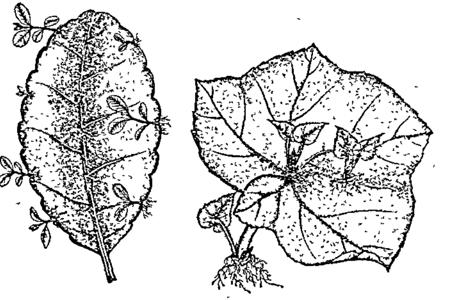


FIG. 15A. Buds.

Protection of the Bud. Since buds have to give rise to flowers,

and branches it is imperative that these should be protected against external injuries—sun, rain, fungi, insects, etc., and this protection is afforded in different ways. (1) The young leaves of the bud normally overlap each other, and remain variously rolled or folded to protect themselves and the growing apex against sun and rain. (2) They may be covered by hairs, or in some cases they remain bathed in resinous or gummy secretions. (3) They remain enclosed in some dry and scaly outer leaves, called **bud-scales**, as in banyan, jack, *Magnolia*, iron-wood tree (*Mesua*; B. NAGESWAR; H. NAGKESAR), etc. (4) There may be a coating of wax or cutin on the leaf-surface to check evaporation of water and to prevent the leaves and the growing apex from getting wet.



B C

FIG. 15 *B-C*. *B*, foliar buds and adventitious roots of *Bryophyllum*; *C*, the same of *Begonia*.

Modification of the Bud. Vegetative buds may be modified into tendrils (see FIG. 19A), as in passion-flower and vine, or into thorns (see FIG. 37), as in *Duranta*, *Carissa*, wood-apple, etc. Sometimes these may become modified into special reproductive bodies, known as bulbils (see p. 27). Floral buds may likewise be modified into tendrils (see FIGS. 35B & 36), as in Sandwich Island climber and balloon vine, or into bulbils (see p. 27) for the purpose of reproduction.

Habit of the Plant. The nature of the stem, the height the plants attain, and the duration and mode of their life determine their habit.

1. **Herbs.** These are small plants with soft stems. According to the duration of their life they may be classified as (1) annuals, (2) biennials, and (3) perennials. (1) Annuals are those plants that attain their

full growth in one season, living for a few months or at the most for one year only. Within this period they produce flowers and seeds and then die off at the end of the season. Common examples are sunflower, mustard, rice, jute, lady's finger, pea, bean. etc. (2) **Biennials** are those plants that live for two years. They attain their full vegetative growth in the first year and they produce flowers and seeds in the second year after which they die off. Common examples are cabbage, radish, beet, carrot, turnip, etc. (in tropical climates they behave like annuals); and (3) **perennials** are those plants that persist for a number of years; the aerial parts of such plants may die down every year at the end of the flowering season but next year again new shoots develop from the underground stem after a few showers of rain, e.g. *Canna*, ginger, arrowroot, etc.

2. **Shrubs.** These are medium-sized plants with hard and woody stems which branch profusely from near the ground so that the plants often become bushy in habit without having a clear trunk. They are larger than herbs, but much smaller than trees, e.g China rose, garden croton, night jasmine, *Duranta*, etc.

3. **Trees.** These are very tall plants with clear trunks and hard and woody stems and profusely branched (except most palms), e.g. mango, jack, teak, *Casuarina* (B. & H. JHAU), country almond, etc. Some trees like *Eucalyptus*, redwood tree (*Sequoia*) and mammoth tree (*Sequoia gigantea*) attain a height of over 90 metres. It may also be noted that *Eucalyptus* lives for about 300 years, and the other two for 1,000-1,500 years. Some conifers have a life-span of 2,500 years.

4. **Climbers.** These have thin and long stems with diffuse branches; they often develop special organs of attachment.

(1) **Rootlet Climbers.** Such plants climb by means of small adventitious roots which often form small adhesive discs or claws to act as *holdfasts* or secrete a sticky juice, as in betel (*Piper betle*; see FIG. 12A), long pepper (*Piper longum*), *Piper chaba*, ivy (*Hedera helix*), Indian ivy (*Ficus pumila*; FIG. 16), wax plant (*Hoya*), *Pothos*, etc.

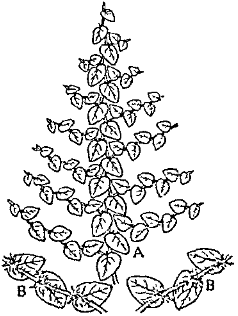


FIG. 16. Indian ivy (*Ficus pumila*)—a rootlet climber; *A*, upper side; *B*, lower side.

(2) **Hook Climbers.** The flower-stalk of *Artabotrys* (B & H. KANTALI-CHAMPA) produces a curved hook (FIG. 17C), which facilitates to some extent the climbing of the branches. Often prickles and thorns are curved and hooked in certain plants. Thus in cane (*Calamus*;

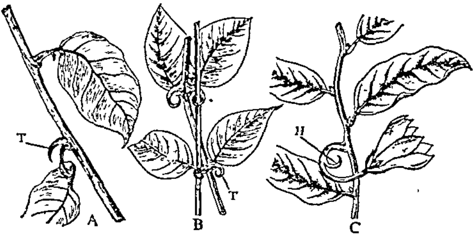


FIG. 17. Hook and Thorn Climbers. *A*, Glory of the garden (*Bougainvillea*); *T*, thorn; *B*, *Uncaria*; *T*, hooked thorn; *C*, *Artabotrys*; *H*, hook.

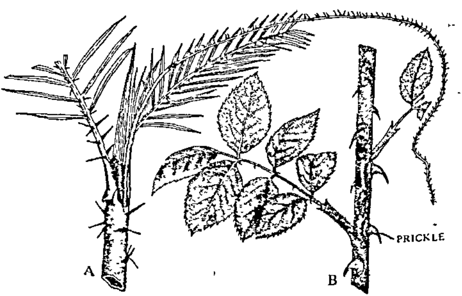


FIG. 18. Prickle Climbers. *A*, cane; *B*, rose.

FIG. 18A) a long slender axis beset with numerous sharp and curved hooks is produced from the leaf-sheath. Climbing rose (FIG. 18B) and *Pisonia* are provided with numerous curved prickles for the purpose of climbing (and also for self-defence). Glory of the garden

wise (sinistrorse) e.g. wild yam (*D. bulbifera*), while others are indifferent in the direction of their movement.

FIG. 20. Leaf Climbers *A*, *Clematis*; *B*, glory lily (*Gloriosa*); *C*, pitcher plant (*Nepenthes*; see also FIG 66).

(6) **Lianes.** These are very thick and woody perennial climbers, commonly met with in forests. They twine themselves round tall trees in search of sunlight, and ultimately reach their tops. There they get plenty of sunlight and produce a canopy of foliage. Common examples are *Hiptage* (B. MADHABI-LATA; H. MADHU-LATA), camel's foot climber (*Bauhinia vahlii*; B. LATA-KANCHAN; H. CHAMBULI—see FIG. 176), etc.

Special Types of Plants. Green plants normally prepare their own carbohydrate food and nourish themselves; such plants are said to be **autophytes** or **autotrophic plants** (*autos*, self; *phyta*, plants; *trophe*, food) or self-nourishing. There are, however, many plants which draw their organic food from different sources; such plants are said to be **heterophytes** or **heterotrophic plants** (*heteros*, different). These are of various kinds.

1. **Parasites.** These are plants that grow upon other living plants or animals and absorb the organic food from the hosts by their sucking roots called **haustoria**. Common examples of different types of parasites are:

(1) Total stem-parasites, e.g. dodder (*Cuscuta*; FIG. 21A).

(2) Partial stem-parasites, e.g. mistletoe (*Viscum*; FIG. 23), *Loranthus* and *Cassytha*.

(3) Total root-parasites, e.g. broomrape (*Orobanche*; B. BANIABAU; H. SARSON-BANDA—FIG. 22A)—parasitic on roots of potato, tomato, brinjal, mustard, tobacco, etc. often doing considerable damage to these crops, *Balanophora* (FIG. 22B)—parasitic on roots of forest trees, *Sapria* (1 sp.)—parasitic on roots of various plants in

Assam, and *Rafflesia* (6 sp.)—parasitic on *Vitis* roots in Java and Sumatra.

FIG. 21. *A*, dodder (*Cuscuta*)—a total stem parasite; *B*, a section through dodder (and the host plant) showing the sucking root (haustorium).

(4) Partial root-parasites, e.g. sandalwood tree (*Santalum*)—found abundantly in Mysore.

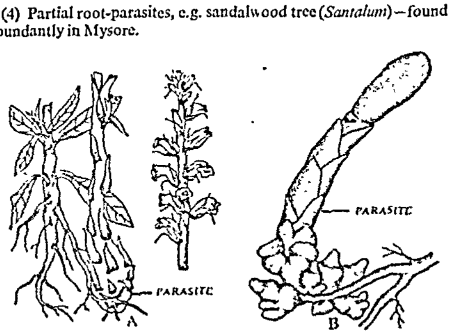


FIG. 22. *A*, broomrape (*Orobanche*)—a total root-parasite; *B*, *Balanophora*—a total root-parasite.

Rafflesia arnoldii (no. 24) is a very interesting plant, inasmuch as it bears the most gigantic flower in the world, measuring ½-1 metre in diameter and weighing

over 8 kg. The plant was first discovered in 1818 by Sir Stamford Raffles, while making a tour in the interior of Sumatra, and was named after him. Altogether six species have been discovered in Sumatra, Java and the neighbouring islands. The flower is of a livid, fleshy colour, and the smell is like that of putrid meat.

Sapria himalayana found only in the Aka, Dafla and Naga hills of Assam is identical with *Rafflesia arnoldi* in all respects excepting that the flower is smaller in size, measuring more or less 30 centimetres in diameter.

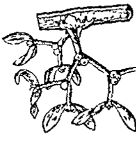


FIG 23. Mistletoe—a partial stem-parasite.

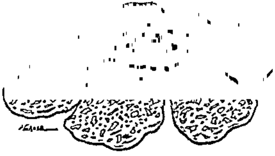


FIG. 24. *Rafflesia*—a total root-parasite.

2. **Epiphytes** (*epi*, upon; *phyta*, plants). These are plants that grow upon other plants (see FIG. 13), but do not suck them, i.e. do not absorb food from them, as do parasites. They usually develop three kinds of roots, viz. *clinging roots*, *absorbing roots* and *hanging roots*. The clinging roots grow into cracks and crevices in the bark of the supporting plant and fix the epiphyte in proper position on the

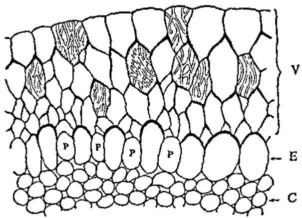


FIG. 25. *Vanda* root in transection showing: *V*, velamen; *E*, exodermis; *P*, passage cell; *C*, cortex.

branch; besides, they act as reservoirs of humus which accumulates in the ne

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special absorptive tissue, called velamen (FIG. 25), which usually con-

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containing air or water o
ings. There are also min ... sort of sponge and absorbs moisture from the surrounding air and also water trickling down the root. Examples are found in many orchids, e.g *Vanda* (B. & H. RASNA—see FIG. 13) and some ferns. Banyan, peepul, etc., are, in their earlier stages, often epiphytic on date-palm and other trees.

3. **Saprophytes** (*sapros*, rotten; *phyta*, plants). These are plants that grow in places rich in decaying organic substances of vegetable or animal origin, and derive their nutriment from them. Fungi and bacteria are either parasites or saprophytes. Among the 'flowering' plants Indian pipe (*Monotropa*; FIG. 26), *Burmannia* and some orchids are good examples of saprophytes. *Monotropa uniflora*, and a few species of *Burmannia*, e.g. *B. disticha*, *B. candida*, etc., grow in the Khasi Hills—*Monotropa* at an altitude of 1,800 metres and *Burmannia* of 1,400 metres. Total saprophytes are colourless, while the partial ones are green in colour. Their roots become associated with a filamentous mass of a fungus which takes the place of and acts as the root-hairs, absorbing food material from the decomposed organic substances present in the soil. The association of a fungus with the root of a higher plant is known as **mycorrhiza** (see below).

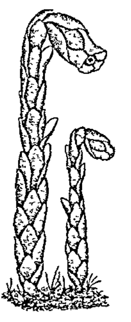

FIG. 26. *Monotropa* —a saprophyte.

4. **Symbionts** (*syn*, together; *bios*, life). When two organisms live together, as if they are parts of the same plant, and are of mutual help to each other, they are called **symbionts**, and the relationship between the two is expressed as **symbiosis**. Lichens are typical examples. These are associations of algae and fungi, and commonly occur as thin round greenish patches on tree-trunks and old walls. The alga in a lichen being green prepares food and shares it with the fungus, while the latter absorbs water and mineral salts from the surrounding medium, and also affords protection to the alga. Among the 'flowering' plants some of the mycorrhizas are good examples of symbiosis.

Mycorrhiza. Mycorrhiza (fungus-root) is the association of a fungus with the root of a higher plant. This association was first discovered by Frank in 1885, who found it to be a regular feature in many species of plants, particularly forest trees (beech, oak, etc.), many conifers (pine, etc.), saprophytic phanerogams, orchid seedlings, etc. The fungus concerned may belong to various classes. The

root does not elongate but frequently branches profusely, and no root-hairs are

all cases and divergent opinions have been given. The relationship may range from true parasitism to genuine symbiosis. In the latter case the fungus absorbs water, mineral salts and nitrogenous organic substances from the soil, and in some cases it even fixes free nitrogen of the air. The fungus also helps respiration of the root, as in pine. In return it receives food from the root. The mycorrhizal fungus particularly benefits certain plants. Thus it is seen that orchid seeds often do not germinate if they are not infected by a particular fungus, and the pine seedlings and orchid seedlings are slow in growth and become weak in the absence of a similar infection.

5. **Carnivorous Plants** (see part III, chapter 7). Carnivorous plants are those that capture insects and small animals, and feed upon them, absorbing only the nitrogenous compounds from their bodies. Such plants are green in colour and prepare their own carbonaceous food, while they partially depend on insects and other animals for nitrogenous food. Some of the examples are sundew, butterwort, Venus' fly-trap, *Aldrovanda*, pitcher plant, bladderwort, etc.

Modifications of Stems

1. **Underground Modifications of Stems.** For the purpose of perennation stems develop underground and lodge there permanently, lying in a dormant, defoliated condition for some time and then giving off aerial shoots annually under favourable conditions. They are

ence of (*a*) nodes and internodes, (*b*) scale-leaves, and (*c*) buds (axillary and terminal). The main function of this group of modified stems is, as already stated, (*a*) perennation; but they are also meant (*b*) to store up food material and (*c*) to propagate, i.e. to multiply plants vegetatively. The various types met with in this group are as follows:

(1) Rhizome (FIG. 27). Rhizome is a prostrate, thickened stem,

creeping horizontally under the surface of the soil. It is provided with distinct nodes and long or short internodes; it bears some scaly leaves at the nodes; it possesses a bud in the axil of the scaly leaf; and it ends in a terminal bud. Some slender, adventitious roots are given off from its lower side. The rhizome may be unbranched or sometimes the axillary buds grow out into short, stout branches. It remains dormant underground and then with the approach of the vegetative season the terminal bud and sometimes also some of the axillary buds grow into the aerial shoots. Its direction is normally horizontal, but sometimes it grows in the vertical direction (root-stock), as in *Alocasia* (B. MAN-KACHU; H. MAN-KANDA). Examples of

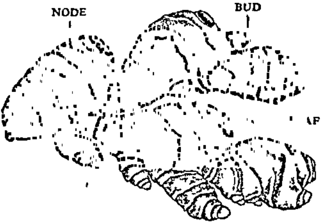

FIG. 27. Rhizome of ginger.

rhizome are seen in *Canna*, ginger, turmeric, arrowroot, water lily, lotus, ferns and many aroids.

(2) Tuber (FIG. 28). This is the swollen end of a special underground branch (tuber means a swelling). The underground branch arises from the axil of a lower leaf, grows horizontally outwards and ultimately swells up at the apex. It has on its surface a number of 'eyes' or buds which grow up into new plants. Adventitious roots which are abundantly formed in other underground stems are usually absent from a tuber. A tuber is often very much swollen owing to a heavy deposit of food material, becoming almost spherical, e.g. potato. Jerusalem artichoke (B. HATICHOKI) is another example.

(3) Bulb (FIG. 29). This is an underground modified shoot (rather a single, often large, terminal bud) consisting of a shortened convex or slightly conical stem, a terminal bud and numerous scale-leaves (which are the swollen bases of foliage leaves). The scale-leaves, often simply cal [illegible] around it, [illegible] from its b [illegible] dry. The scales may occur surrounding the stem in concentric rings, as in onion, leek, garlic, tuberose, most lilies, etc., or they may be

is said to be *tunicated* or *coated*, while the latter is rather rare and i

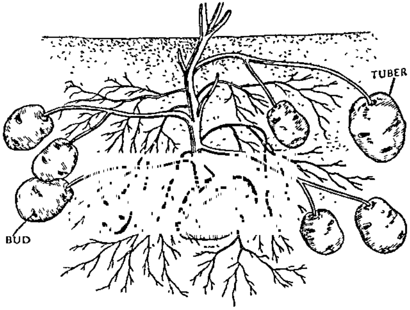

FIG. 28. Tubers of potato.

said to be *scaly*. The fleshy scales store food (sugar in onion and mostly starch in others), while the dry scales give protection. The

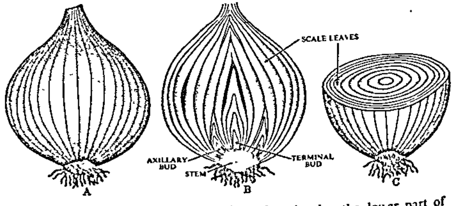

FIG. 29. Bulb of onion. *A*, an entire onion showing the lower part of the bulb with adventitious roots, and outer dry scale-leaves with distinct veins; *B*, an onion cut longitudinally; and *C*, an onion cut transversely.

bulb is vertical in direction and its terminal bud gives rise to the aerial shoot. Some axillary buds may also be produced in the axils of fleshy scales. These may develop into aerial shoots and finally form

daughter bulbs or they may remain dormant. The daughter bulbs grow in the following season.

(4) **Corm** (FIG. 30). This is a condensed form of rhizome consisting of a stout, solid, fleshy, underground stem growing in the vertical direction. It is more or less rounded in shape or often somewhat flattened from top to bottom. It contains a heavy deposit of food

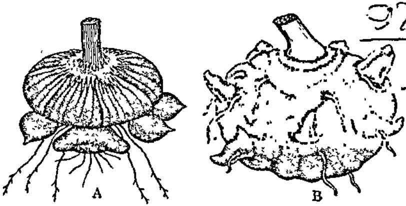

FIG. 30. *A*, corm of *Gladiolus*; *B*, corm of *Amorphophallus*.

material and often grows to a considerable size. It bears one or more buds in the axils of scale-leaves, and some of these buds grow up into daughter corms. Adventitious roots normally develop from the base but sometimes also from the sides. Corm is found in *Amorphophallus* (B. OL; H. KANDA), *Gladiolus*, taro (*Colocasia*), saffron (*Crocus*) and meadow saffron (*Colchicum*).

2. **Sub-aerial Modifications of Stems.** These are meant for vegetative propagation and are of the following kinds:

(1) **Runner** (FIG. 31). This is a slender, prostrate branch with long

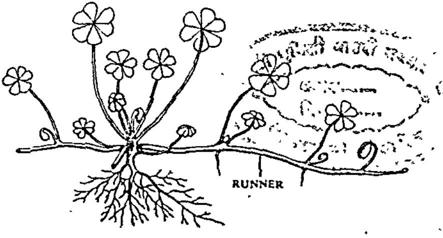

FIG. 31. Runner of wood-sorrel (*Oxalis*).

internodes, creeping on the ground and rooting at the nodes. The runner arises as an axillary bud and creeps some distance away from the mother plant, then strikes roots and grows into a new plant. Many such runners are often produced by the mother plant and they spread out on the ground on all sides. They may break off from the mother plant and grow up as independent daughter plants. Examples are seen in wood-sorrel (*Oxalis*), *Marsilea*, strawberry, Indian pennywort (see FIG. III/55), etc.

(2) **Stolon** (FIG. 32). This is a slender lateral branch originating from an underground stem and growing horizontally outwards for shorter or longer distances. It is often provided with nodes and internodes. Many such branches may grow out in different directions and at length their end (terminal bud) emerges out of the ground and develops into a new plant. The stolon resembles a runner in all respects excepting that it is subterranean, while the runner is subaerial. Examples of the stolon are seen in taro, arrowroot, passion-flower, some jasmines, *Tecoma grandiflora*—an ornamental garden climber.

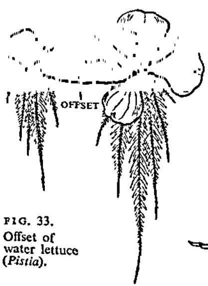

FIG. 33. Offset of water lettuce (*Pistia*).

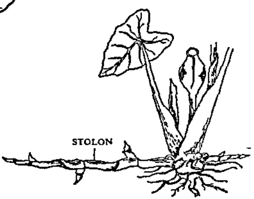

FIG. 32. Stolon of taro (*Colocasia*).

(3) **Offset** (FIG. 33). Like runners this originates in the axil of a leaf as a short, more or less thickened, horizontal branch. It elongates only to a certain extent and produces at the apex a tuft of leaves above and a cluster of small roots below. The offset often breaks away from the mother plant and then the daughter plant embarks on a separate career. Common examples are water lettuce (*Pistia*) and water hyacinth. An offset is shorter and stouter than a runner, and is found only in the rosette type of plants.

(4) **Sucker** (FIG. 34). Like the stolon the sucker is also a lateral

branch developing from the underground part of the stem. But it grows obliquely upwards and directly gives rise to a leafy shoot or a new plant. Occasionally it grows horizontally outwards only to a certain extent, but soon it turns up, as in *Chrysanthemum*, or it may be shorter and stouter, as in banana. In any case a sucker is always much shorter than a stolon. Examples of sucker are seen in *Chrysanthemum*, banana, pineapple, bamboo, mint, etc.

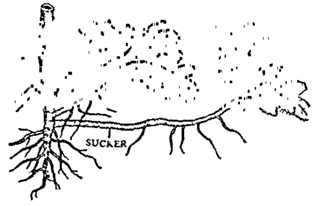

FIG. 34. Suckers of *Chrysanthemum*.

3. **Aerial Modifications: Metamorphoses.** Vegetative and floral buds which would normally develop into branches and flowers, often undergo extreme degrees of modification (metamorphosis) in certain plants for definite purposes. Metamorphosed organs are stem-tendril for climbing, thorn for protection, phylloclade for food manufacture, and bulbil for vegetative reproduction.

(1) **Stem-tendril** (FIGS. 35-6). This is a thin, wiry, leafless, spirally-

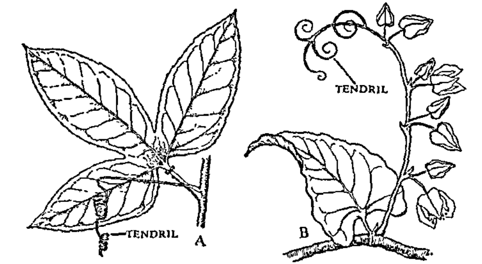

FIG. 35. Stem-tendrils. *A*, tendril of passion-flower (*Passiflora*); *B*, tendrils of Sandwich Island climber (*Antigonon*).

curled branch, by which climbers attach themselves to neighbouring objects and climb them. Stem-tendrils are seen in vine (*Vitis*)

passion-flower, etc. In passion-flower the axillary bud is modified into the tendril, and in *Vitis* it is the terminal bud that becomes so modified. Sometimes, as in Sandwich Island climber (*Antigonon*=*Corculum*; FIG. 35B) and balloon vine (*Cardiospermum*; FIG. 36), floral buds are modified into tendrils.

FIG. 36. Tendrils of balloon vine (*Cardiospermum*). *T*, a tendril.

(2) Thorn (FIG. 37). The thorn is a hard, often straight and pointed structure. It is regarded as a modified branch because it arises in the axil of a leaf or sometimes at the apex of a branch, which is the normal position of a bud. Thus in *Duranta*, lemon, pomegranate, etc., the axillary bud is modified into a thorn, and in *Carissa* (B. KARANJA; H. KARONDA) the terminal bud is modified into a pair of

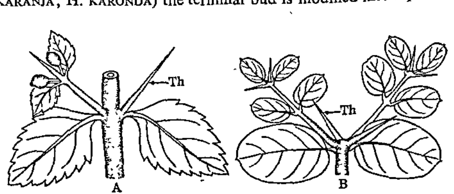

FIG. 37. Thorns. *A*, *Duranta*; *B*, *Carissa*. *Th*, thorn.

thorns. The thorn sometimes bears leaves, flowers and fruits, as in *Duranta* and prune (*Prunus*), and not infrequently it becomes branched, as in *Flacourtia* (B. & H. PANIALA).

Differences between Thorns and Prickles. Both the thorns and the prickles are primarily defensive organs being sharp and pointed; they also sometimes act as climbing organs Their morphological differences are: a thorn is a modification

distribution occurring in any part of the stem, branch or even leaf. Further a thorn is deep-seated; while a prickle is superficial in origin. Thorns are found in wood-apple, *Duranta*, etc., and prickles in rose, coral tree, etc.

(3) **Phylloclade** (FIG. 38). The phylloclade is a green, flattened or rounded stem. Being green it has the functions of the leaves which are

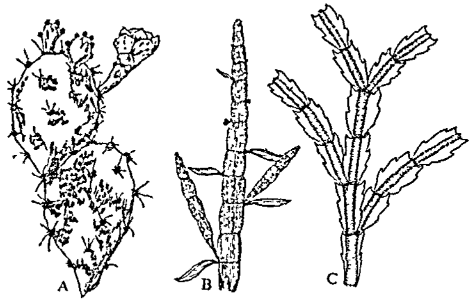

FIG. 38. Phylloclades. *A*, prickly pear (*Opuntia*); *B*, cocoloba; *C*, *Epiphyllum*.

seen to be either feebly developed or modified into spines. Examples are found in many cacti such as prickly pear (*Opuntia*; B. PHANIMANSHA; H. NAGPHANI—*A*), cocoloba—*B*, night-blooming cacti (*Cereus* and *Phyllocactus*) and *Epiphyllum*—*C*, *Casuarina*, some species of *Euphorbia* (B. & H. SIJ), etc. The phylloclade of one internode is spoken of as the cladode (FIG. 39), as in *Asparagus*. Duckweed (*Lemna*; see FIG. 2D) is another common example of a cladode.

(4) **Bulbil** (see FIGS. III/58-62). The bulbil is a special multicellular body essentially meant for the reproduction of the plant. It may be the modification of a vegetative bud or of a floral bud. In any case it detaches itself from the mother plant and grows up into a new independent one. Bulbils are seen in *Dioscorea bulbifera*, *Oxalis*, *Globba bulbifera*, *Agave*, onion, *Lilium bulbiferum*, etc.

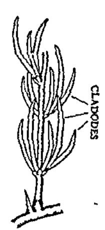

FIG. 39. Cladodes of *Asparagus*.

Branching

The mode of arrangement of the branches on the stem is known as **branching**. There are two principal types of branching, viz. lateral and dichotomous.

A. LATERAL BRANCHING

When the branches are produced laterally, that is, from the sides of the main stem, the branching is called **lateral**. The lateral branching may be racemose or indefinite or monopodial (*monos*, one; *pod-*, foot or axis) and cymose or definite.

1. **Racemose Type.** Here the growth of the main stem is indefinite, that is, it continues to grow indefinitely by the terminal bud and give off branches laterally in *acropetal* succession, i.e. the lower branches are older and longer than the upper ones (FIG. 40A). Branching of this type is also called **monopodial** because there is a single continuous

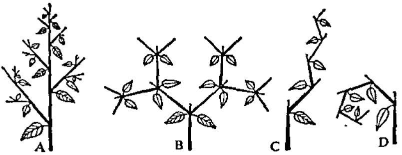

FIG. 40. Types of Branching. *A*, racemose type; *B*, true (biparous) cyme; *C*, scorpioid cyme; *D*, helicoid cyme.

axis, as in *Casuarina*, mast tree (*Polyalthia*), etc. As a result of this branching the plant takes on a conical or pyramidal shape.

2. **Cymose Type.** Here the growth of the main stem is definite, that is, the terminal bud does not continue to grow, but lower down, the main stem produces one or more lateral branches which grow more vigorously than the terminal one. The process may be repeated over and over again. As a result of cymose branching the plant spreads out above, and becomes more or less dome-shaped. Cymose branching may be of the following kinds:

[illegible]

coid or one-sided cyme (FIG. 40D), when successive lateral branches develop on the same side, forming a sort of helix, as in *Saraca* (B. ASOK; H. SEETA ASHOK), and (*b*) **scorpioid** or alternate-sided cyme (FIG. 40C), when successive lateral branches develop on alternate sides, forming a zig-zag, as in vine (*Vitis vinifera*), wild vine (*V. trifolia*), *Cissus quadrangularis* (B. & H. HARHJORA), etc. In them the

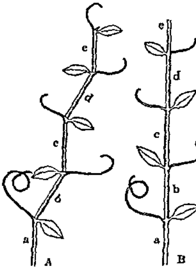

FIG. 41

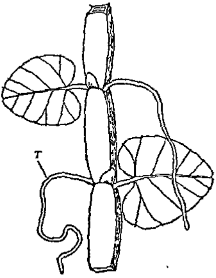

FIG. 42

nal ten-
a-e are
f *Cissus*

apparent or false axis (**sympodium**) is a succession of lateral axes, and the tendrils are modified terminal vegetative buds (FIGS. 41-2).

(2) **Biparous Cyme.** If, in the cymose branching, two lateral axes develop at a time, it is called biparous or dichasial (FIG. 40B). Examples are seen in mistletoe (see FIG. 23), four o'clock plant, pagoda tree, *Datura*, *Carissa* (see FIG. 37B), etc.

(3) **Multiparous Cyme.** If more than two branches develop at a time, the branching is said to be multiparous or polychasial, as in *Croton sparsiflorus* and some species of *Euphorbia*.

B. DICHOTOMOUS BRANCHING

When the terminal bud bifurcates, that is, divides *into two*, producing two branches in a forked manner, the branching is termed dichotomous. Dichotomous branching is common among the 'flowerless' plants, as in *Riccia* (FIG. 43), *Marchantia* (see FIG. V/95), [illegible] *phlegmaria* (an epiphytic *Lycopodium*; see FIG. V/122), etc. [illegible]

the 'flowering' plants examples are afforded by *Hyphaene* (a kind of palm), screwpine (*Pandanus*), *Canscora* (a weed), etc.

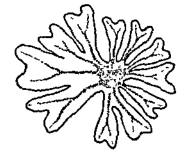

FIG. 43. Dichotomous branching in *Riccia*

Functions of the Stem. The main purpose of the stem is to bear leaves and flowers and spread them out on all sides for proper functioning—the leaves to get the adequate amount of sunlight for manufacture of food material, and the flowers to attract insects from a distance for the purpose of pollination and reproduction. Other functions are support of the branches which push forward the leaves and the flowers, conduction of water, mineral salts and prepared food through the plant body, storage of water and food in many cases, and manufacture of food by the young green shoot.

Chapter 3 THE LEAF

The leaf may be regarded as the flattened, lateral outgrowth of the stem or the branch, developing from a node and having a bud in its axil. It is normally green in colour and is regarded as the most important vegetative organ of the plant since food material is prepared in it. Leaves always follow an *acropetal* order of development and are *exogenous* in origin.

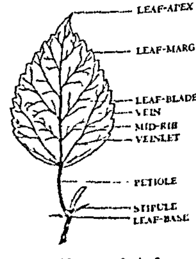

FIG. 44. Parts of a leaf.

Parts of a Leaf (FIG. 44). A typical leaf consists of the following parts, each with its own function. (1) **Leaf-base** is the part attached to the stem. In monocotyledons the leaf-base commonly expands into a sheath which partially or wholly clasps the stem, while in many dicotyledons the leaf-base bears two lateral outgrowths, known as the stipules. In *Leguminosae* and also in many other plants the leaf-base

is swollen, and then it is known as the **pulvinus** (FIG. 45A). (2) **Petiole** is the stalk of the leaf. A long petiole pushes out the leaf-blade and thus helps it to secure more sunlight. When the petiole is absent the leaf is said to be **sessile**; and when present it is said to be **petiolate** or stalked. Commonly the petiole is cylindrical being terete or grooved, but in many cases the petiole shows certain peculiarities. Thus in water hyacinth (FIG. 45B) it swells into a spongy bulb, often called pseudo-bulb, containing innumerable air-chambers for facility of floating; while in orange, pummelo or shaddock, etc., it becomes winged (FIG. 45C). In Australian *Acacia* (see FIG. 65) it is modified into a flattened sickle-shaped lamina or blade, called phyllode. In *Clematis* (see FIG. 20A) the petiole is tendrillar in nature. (3) **Leaf-blade** or **lamina** is the green, expanded portion. A strong vein, known

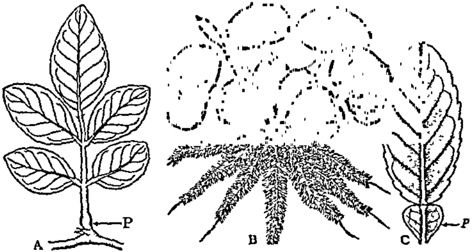

FIG. 45. *A*, *Clitoria* leaf showing pulvinus (P); *B*, water hyacinth leaf showing bulbous petiole; *C*, pummelo leaf showing winged petiole (*P*).

as the **mid-rib**, runs centrally through the leaf-blade from its base to the apex; this produces thinner lateral veins which in their turn give rise to still thinner veins or veinlets. The lamina is the most important part of the leaf since this is the seat of food-manufacture for the entire plant. Its external and internal organization is well adapted for this purpose as well as for other functions it has to perform.

When the lobes at the base of the leaf partially enclose the stem, the leaf is said to be **auriculate** (*auricle*, lobe), as in madar (*Calotropis*), *Sonchus*, etc.; when completely, it is called **amplexicaul** (*amplexus*, embrace; *caulis*, stem), as in grass, wheat and cauline leaves of *Emilia*; when incompletely, it is called **semi-amplexicaul**, as in buttercup, palms, etc.; when the lobes meet across the stem and fuse together so that the latter seems to pass through the leaf-blade, the leaf is said to be **perfoliate** (*per*, through; *folium*, a leaf), as in *Canscora perfoliata*, *Aloe*

perfoliata, etc. When two sessile opposite leaves meet each other across the stem and fuse together, they are said to be connate, as in *Canscora diffusa* (B. DANKUNI) and wild honeysuckle (*Lonicera flava*). In some cases, as in *Laggera pterodonta*,

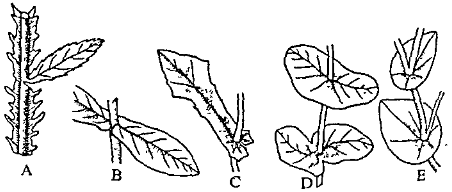

FIG. 46 Sessile Leaves. *A*, decurrent leaf of *Laggera pterodonta*; *B*, auriculate leaves of madar (*Calotropis*); *C*, amplexicaul leaf of *Emilia sonchifolia*; *D*, connate leaves of *Lonicera flava*; *E*, perfoliate leaves.

Laggera alata, *Canscora decurrens*, *Crotalaria alata* and some of the thistles, the petiole and the leaf-base become winged, and this wing extends down the stem so that the latter also seems to be winged; a leaf of this nature is said to be **decurrent**.

Stipules

Stipules are the lateral appendages of the leaf borne at its base. Their function is to protect the young leaves in the bud, and when green they manufacture food material in the same way as leaves. When stipules are present the leaf is said to be **stipulate**, and when absent [illegible] *ria*; B. APARAJITA; [illegible] ase of each leaflet. [illegible]

Kinds of Stipules (FIG. 47). According to their shape, position, colour and size, the stipules are of the following kinds:

(1) **Free Lateral Stipules** (see FIG. 44). These are two free stipules, usually small and green in colour, borne on the two sides of the leaf-base, as in China rose, cotton, etc.

(2) **Scaly Stipules.** These are small dry scales, usually two in number, borne on the two sides of the leaf-base, as in *Desmodium*, e g. Indian telegraph plant (*Desmodium gyrans*).

(3) **Adnate Stipules** (C). These are the two lateral stipules that grow along the petiole up to a certain height, adhering to it and making it somewhat winged in appearance, as in rose, groundnut or peanut, strawberry and lupin.

(4) **Interpetiolar Stipules** (B). These are the two stipules that lie between the petioles of opposite or whorled leaves, thus alternating with the latter. They are seen in *Ixora*, *Anthocephalus* (B. & H. KADAM), *Vangueria* (B. MOYENA; H. MOINA), etc. Sometimes, as in cape jasmine (*Gardenia*; B. & H. GANDHARAJ), the two stipules are axillary in position, each lying between the petiole and the stem; they are then known as the **intrapetiolar stipules**.

(5) **Ochreate Stipules** (A). They form a hollow tube encircling the stem from the node up to a certain height of the internode in front of the petiole, as in *Polygonum*, sorrel (*Rumex*) and buckwheat (*Fagopyrum*).

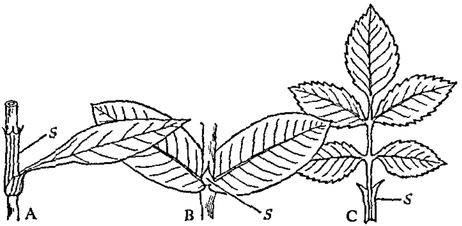

FIG. 47. Kinds of Stipules. *A*, ochreate stipule (*S*) of *Polygonum*; *B*, interpetiolar stipule (*S*) of *Ixora*; *C*, adnate stipule (*S*) of rose.

(6) **Foliaceous Stipules** (see FIG. 61A-B). These are two large, green, leafy structures, as in pea (*Pisum*), wild pea (*Lathyrus*) and some varieties of passion-flower.

(7) **Bud-scales.** These are scaly stipules which enclose and protect the vegetative buds, and fall off as soon as the leaves unfold. They are seen in banyan, jack, *Magnolia*, iron-wood tree (*Mesua*; B. NAGESWAR; H. NAGKESAR), etc.

Modified Forms of Stipules. Stipules are sometimes modified into spines and tendrils, and perform functions peculiar to these two structures. (1) **Spinous stipules** (FIG. 48). In some plants, as in gum tree (*Acacia*), Indian plum (*Zizyphus*), sensitive plant (*Mimosa*), caper (*Capparis*), etc., the stipules become modified into two sharp pointed structures known as spines, one on each side of the leaf-base. Such spinous stipules give protection to the leaf against the attack of herbivorous animals. (2) **Tendrillar stipules** (FIG. 49). In sarsaparilla (*Smilax*) the stipules become modified into two strong closely-coiled tendrils, one on each side of the petiole. These tendrillar stipules help

the plant to climb neighbouring shrubs and trees. Although the ten-

FIG. 48 Spinous stipules of Indian plum (*Zizyphus*).

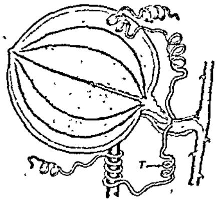

FIG. 49. Tendrillar stipules (*T*) of *Smilax*.

drils in *Smilax* (a monocotyledon) are commonly regarded as modified stipules, stipules are scarcely found in monocotyledons.

Leaf-Blade

Apex of the Leaf (FIG. 50). The apex of the leaf is said to be (1) **obtuse**, when it is rounded, as in banyan (*Ficus bengalensis*); (2) **acute**, when it is pointed in the form of an acute angle, but not stiff, as in China rose; (3) **acuminate** or **caudate**, when it is drawn out into a long slender tail, as in peepul (*Ficus religiosa*) and lady's umbrella (*Holmskioldia*); (4) **cuspidate**, when it ends in a long rigid sharp (spiny) point, as in date-palm, screwpine and pineapple; (5) **truncate**, when it ends ab-

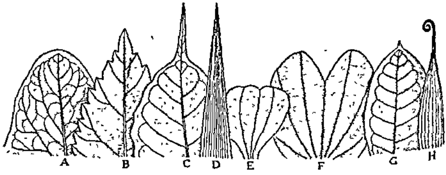

FIG. 50. Apex of the leaf. *A*, obtuse; *B*, acute; *C*, acuminate; *D*, cuspidate; *E*, retuse; *F*, emarginate; *G*, mucronate; and *H*, cirrhose.

when the apex is provided with a deep notch, as in *Bauhinia* (B. KANCHAN; H.

KACHNAR) and wood-sorrel (*Oxalis*); (8) mucronate, when the rounded apex abruptly ends in a short point, as in *Ixora* (B. RANGAN; H. GOTAGANDHAL); and (9) cirrhose (*cirrus*, a tendril or a curl), when it ends in a tendril, as in glory lily, or in a slender, curled, thread-like appendage, as in banana.

Margin of the Leaf. The margin of the leaf may be (1) entire, i e. even and smooth, as in mango, jack, banyan, etc.; (2) repand, i.e. shallowly wavy or undulating, as in mango; (3) sinuate, i.e. deeply undulating, as in mast tree (*Polyalthia*; B. DEBDARU; H. ASHOK) and some garden crotons; (4) serrate, i e. cut like the teeth of a saw and the teeth directed upwards, as in China rose, rose, or margosa (*Melia*; B. & H. NIM or NIMBA); (5) biserrate, i e. doubly serrate (each tooth serrated again); (6) serrulate, i.e. minutely serrate; (7) dentate, i.e. the teeth directed outwards at right angles to the margin of the leaf, as in melon and water lily; (8) runcinate, i e. serrated with the teeth pointed backwards; (9) crenate, i.e. the teeth rounded, as in sprout leaf plant (*Bryophyllum*) and Indian pennywort (*Centella*); (10) fimbriate, i e. fringed with fine segments; (11) ciliate, i e. fringed with hairs; and (12) spinous, i.e. provided with spines, as in prickly poppy (*Argemone*; see FIG. 64B).

Surface of the Leaf. The leaf is said to be (1) glabrous, when its surface is smooth and free from hairs or outgrowths of any kind; (2) rough, when the surface is somewhat harsh to touch; (3) glutinous, when the surface is covered with a sticky exudation, as in tobacco; (4) glaucous, when the surface is green and shining; (5) spiny, when it is provided with spines; and (6) hairy, when it is covered, densely or sparsely, with hairs. Hairy surface may be (*a*) pubescent, when it is covered with short, soft, straight hairs; (*b*) pilose, i.e. thinly covered with long, soft hairs; (*c*) villous, i.e. thickly covered with long, soft hairs; (*d*) tomentose, i.e. densely covered with short, soft, more or less tangled hairs like cotton; (*e*) floccose, i.e. cottony with locks of hairs easily detachable; (*f*) hispid, i.e. beset with rigid or bristly hairs; (*g*) hirsute, i.e. covered with long, coarse, stiff hairs.

Shape of the Leaf (FIG. 51). *A*. Acicular, when the leaf is long, narrow and cylindrical, i.e. needle-shaped, as in pine, onion, etc. *B*. Linear, when the leaf is long, narrow and flat, as in many grasses, tuberose, *Vallisneria*, etc. *C*. Lanceolate, when the shape is like that of a lance, as in bamboo, oleander, mast tree, etc. *D*. Elliptical or oval, when the leaf has more or less the shape of an ellipse, as in *Carissa* (B. KARANJA; H. KARONDA), periwinkle, guava, rose-apple, etc. *E*. Ovate, when the blade is egg-shaped, i e. broader at the base than at the apex, as in China rose, banyan, etc. When the leaf is inversely heart-shaped it is said to be obovate, as in country almond and jack. *F*. Oblong, when the blade is wide and long, with the two margins running straight up, as in banana. *G*. Rotund or orbicular, when the blade is circular in outline, as in lotus, garden nasturtium, etc. *H*. Cordate, when the blade is heart-shaped, as in betel, *Peperomia*, etc., When the leaf is inversely heart-shaped it is said to be obcordate, as in wood-sorrel. *I*. Reniform, when the leaf is kidney-shaped, as in Indian pennywort. *J*. Oblique, when the two halves of a leaf are unequal, as in *Begonia*. In margosa (B. & H. NIM) and Indian cork tree (B. & H. AKAS-NIM), Persian lilac (B. GHORA-NIM), etc., the leaflets

are oblique. *K.* Spathulate, when the shape is like that of a spatula, i.e. broad and somewhat rounded at the top and narrower towards

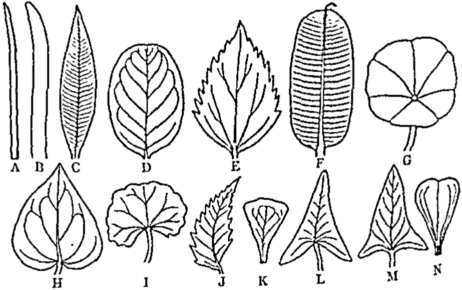

FIG. 51. Shape of the Leaf. *A*, acicular; *B*, linear; *C*, lanceolate; *D*, elliptical or oval; *E*, ovate; *F*, oblong; *G*, rotund or orbicular; *H*, cordate; *I*, reniform; *J*, oblique; *K*, spathulate; *L*, sagittate; *M*, hastate; and *N*, cuneate.

the base, as in sundew (*Drosera*) and *Calendula*. *L.* Sagittate, when the blade is shaped like an arrow, as in arrowhead and some aroids. *M.* Hastate, when the two lobes of a sagittate leaf are directed outwards, as in water bindweed (B. & H. KALMI-SAK) and *Typhonium* (B. GHET-KACHU). *N.* Cuneate, when the leaf is wedge-shaped, as in water lettuce (*Pistia*). *O.* Falcate, when the leaf is sickle-shaped, as in *Eucalyptus globulus* and *Arundinaria falcata* (a bamboo). In Australian *Acacia* the phyllode is falcate. *P.* Lyrate, when the shape is like that of a lyre, i.e. with a large terminal lobe and some smaller lateral lobes, as in radish, mustard, etc. *Q.* Pedate, when the leaf is like the claw of a bird, with the lobes spreading outwards.

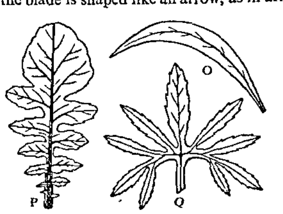

FIG. 51. (*contd.*). *O*, falcate leaf of *Eucalyptus globulus*, *P*, lyrate leaf of radish; *Q*, pedate leaf of *Vitis pedata*.

Venation

Veins are rigid, linear structures which arise from the petiole and the mid-rib and traverse the leaf-lamina in different directions; they are really vascular ramifications made of conducting and mechanical tissues—the former serving to distribute the water and dissolved mineral salts through the lamina and to carry away the prepared food from it, and the latter to give the necessary amount of strength and rigidity to the thin, flat leaf-lamina.

The arrangement of the veins and the veinlets in the leaf-blade is known as venation. There are two principal types of venation, viz.

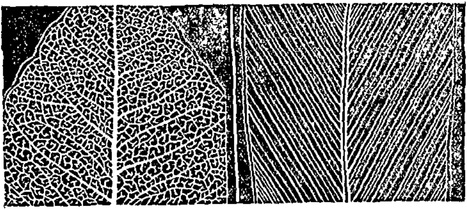

FIG. 52. Systems of Veins. *A*, reticulate venation in a dicotyledonous leaf; *B*, parallel venation in a monocotyledonous leaf.

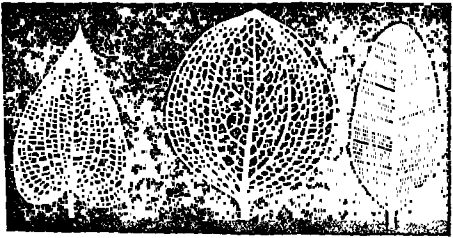

FIG. 53. *A*, leaf of *Dioscorea* (a monocotyledon) showing reticulate venation; *B*, leaf of *Smilax* (a monocotyledon) showing reticulate venation; *C*, leaf of *Calophyllum* (a dicotyledon) showing parallel venation.

reticulate, when the veinlets are irregularly distributed, forming a network; and parallel, when they run parallel to each other. The former is characteristic of dicotyledons and the latter of monocotyledons.

Exceptions: Among monocotyledons sarsaparilla (*Smilax*), aroids, yams (*Dioscorea*), etc., show reticulate venation (FIG. 53A-B) and among dicotyledons Alexandrian laurel (*Calophyllum*; B. & H. SULTANA-CHAMPA—FIG. 53C) and a few others show parallel venation.

I. RETICULATE VENATION

1. **Pinnate or Unicostate Type** (*unus*, one; *costa*, a rib). In this type of venation there is a strong mid-rib or costa; this gives off lateral veins which proceed towards the margin or apex of the leaf, like plumes in a feather (FIG. 54A). These are then connected by smaller veins which pass in all directions, forming a network, as in peepul, mango, guava, etc.

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leaf, as in Indian plum, bay leaf, etc.

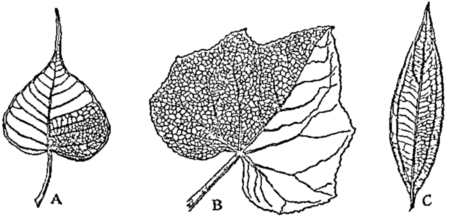

FIG. 54. Types of Reticulate Venation. *A*, pinnate type in peepul leaf; *B*, palmate (divergent) type in cucumber leaf; *C*, palmate (convergent) type in bay leaf.

II. PARALLEL VENATION

1. **Pinnate or Unicostate Type** (FIG. 55A). In this type of venation the leaf has a prominent mid-rib, and this gives off lateral veins which

proceed parallel to each other towards the margin or apex of the leaf-blade, as in plantain, ginger, *Canna*, turmeric, etc.

2. **Palmate Type.** Two forms are also met with here: (1) the veins arise from the tip of the petiole and proceed (diverge) towards the margin of the leaf-blade in a more or less parallel manner (divergent type; FIG. 55C), as in fan palms such as palmyra-palm; and (2) a number of more or less equally strong veins proceed from the base of the leaf-blade to its apex in a somewhat parallel direction (convergent type; FIG. 55B), as in water hyacinth, grasses, rice, bamboo, etc.

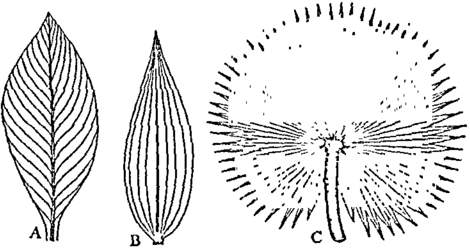

FIG. 55. Types of Parallel Venation. *A*, pinnate type in *Canna* leaf; *B*, palmate (convergent) type in bamboo leaf; *C*, palmate (divergent) type in palmyra-palm leaf.

Functions of the Veins. Veins are rigid structures and their mechanical functions are to give necessary strength to the leaf-blade so that it may not get torn or crumpled when a strong wind blows, and at the same time to help the leaf-blade to keep flat so that its surface may be evenly illuminated by sunlight. A very important physiological function of the veins is to carry water and inorganic salts to the leaf-blade and finally from there the prepared food material into the main body of the plant, particularly the storage organs.

Incision of the Leaf-blade. In the pinnately veined leaf the incision or cutting of the leaf-blade proceeds from the margin towards the mid-rib (pinnate type), and in the palmately veined leaf it passes towards the base of the leaf-blade (palmate type).

First Series: **Pinnate Type.** (1) **Pinnatifid**, when the incision of the margin is half-way or nearly half-way down towards the mid-rib, as in poppy. (2) **Pinnatipartite**, when the incision is more than half-way down towards the mid-rib, as in radish, mustard, etc. (3) **Pinnatisect**, when the incision is carried down to near the mid-rib, as in some ferns, *Quamoclit* (B. KUNJALATA or TORULATA; H. KAMALATA), *Cosmos*, etc. (4) **Pinnate compound**, when the incision of the margin reaches

the mid-rib, thus dividing the leaf into a number of segments or leaflets, as in pea, gram, etc.

Second Series. Palmate Type. (1) Palmatifid, as in passion-flower, cotton, etc. (2) Palmatipartite, as in castor, papaw, etc. (3) Palmatisect, as in tapioca, hemp (*Cannabis*; B & H GANJA) and some aroids, e.g., snake plant (see FIG. 80). (4) Palmate compound, when the incision is carried down to the base of the leaf-blade, as in silk cotton tree

Compound Leaves: Pinnate and Palmate

Simple Leaf and Compound Leaf. A leaf is said to be simple when it consists of a single blade which may be entire or incised (and, therefore, lobed) to any depth, but not down to the mid-rib or the petiole; and a leaf is said to be compound when the incision of the leaf-blade goes down to the mid-rib (rachis) or to the petiole so that the leaf is broken up into a number of segments, called leaflets, these being free from one another, that is, not connected by any lamina, and more or less distinctly jointed (articulated) at their base. A bud (axillary bud) is present in the axil of a simple or a compound leaf, but it is never present in the axil of the leaflet of a compound leaf. There are two types of compound leaves, viz. pinnate and palmate.

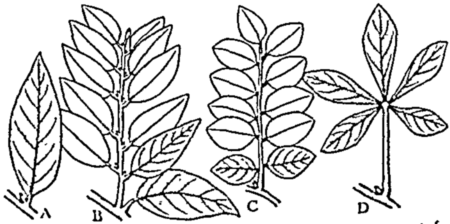

FIG. 56. *A*, a simple leaf; *B*, a branch; *C*, a pinnately compound leaf with the leaflets articulated to the mid-rib; *D*, a palmately compound leaf with the leaflets articulated to the petiole. Note the position of the bud in each case.

Compound Leaf and Branch. A compound leaf may be distinguished from a branch by the following facts: (1) a compound leaf never bears a terminal bud, whereas a branch always does so; (2) a com-

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position of a leaf—simple or compound—developing directly from

the said bud; (3) the leaflets of a compound leaf have no axillary buds; whereas the leaves (simple) borne on a branch have a bud in their axil; and (4) a branch is always provided with nodes and internodes; while the rachis of a compound leaf is free from them.

1. Pinnately Compound Leaf. A pinnately compound leaf is defined as the one in which the mid-rib, known as the **rachis**, bears *laterally* a number of leaflets, arranged alternately or in an opposite manner, as in tamarind, gram, gold mohur, rain tree, sensitive plant, gum tree (*Acacia*), *Cassia*, etc. It may be of the following types:

(1) **Unipinnate.** When the mid-rib of the pinnately compound leaf bears the leaflets directly, it is said to be unipinnate, as in rose, margosa (B. & H. NIM or NIMBA), etc. When the leaflets are even in number the leaf is said to be **paripinnate** (FIG. 58A), as in tamarind, *Abrus*, *Sesbania*, *Saraca*, *Cassia*, etc., and when the leaflets are odd in number the leaf is said to be **imparipinnate** (FIG. 58B), as in rose, margosa, Chinese box (*Murraya*), etc.

The pinnate leaf is said to be unifoliate, when it consists of only one leaflet, as in *Desmodium gangeticum*; bifoliate or unijugate (one pair), when of two leaflets, as in *Balanites* (B. HINGON; H. HINGOL; FIG. 57) and sometimes in rose; trifoliate or ternate, when of three leaflets, as in bean, coral tree and *Vitis trifolia*. It may similarly be quadrifoliate, pentafoliate or multifoliate, according as the leaflets are four, five or more in number. Leaflets also may vary in number on the same plant.

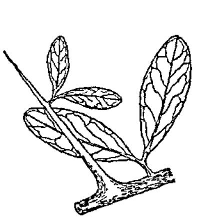


FIG. 57. Bifoliate leaf of *Balanites*.

(2) **Bipinnate** (FIG. 58C). When the compound leaf is twice pinnate,

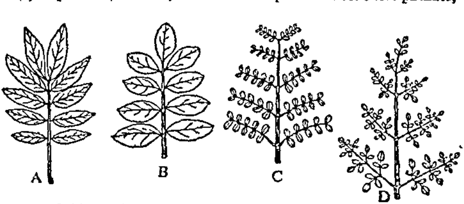


FIG. 58. Pinnate Leaves. *A*, unipinnate (paripinnate); *B*, unipinnate (imparipinnate); *C*, bipinnate; *D*, tripinnate.

i.e. the mid-rib produces secondary axes which bear the leaflets, it is said to be bipinnate, as in dwarf gold mohur, gum tree (*Acacia*), sensitive plant (*Mimosa*), etc.

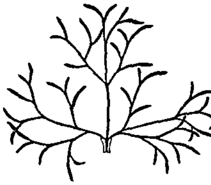


FIG. 59. Decompound leaf of coriander.

(3) **Tripinnate** (FIG. 58D). When the leaf is thrice pinnate, i.e. the secondary axes produce the tertiary axes which bear the leaflets, the leaf is said to be tripinnate, as in drumstick (*Moringa*; B. SAJINA; H. SAINJNA) and *Oroxylon* (B. SONA; H. ARLU).

(4) **Decompound** (FIG. 59). When the leaf is more than thrice pinnate, it is said to be decompound, as in anise, carrot, coriander, *Cosmos*, etc.

2. **Palmately Compound Leaf.** A palmately compound leaf is defined as the one in which the petiole bears *terminally*, articulated to it, a number of leaflets which seem to be radiating from a common point like fingers from the palm, as in silk cotton tree, lupin, *Gynandropsis* and *Polanisia* (=*Cleome*).

According to the number of leaflets it may be **unifoliate**, when a single leaflet is articulated to the petiole, as in shaddock or pummelo,

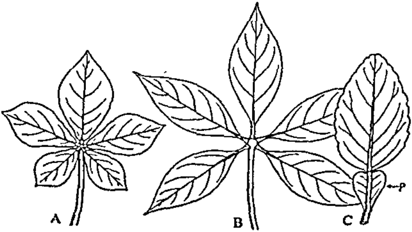


FIG. 60. Palmate Leaves. *A*, digitate leaf of *Gynandropsis*; *B*, the same of silk cotton tree (*Bombax*); *C*, unifoliate compound leaf of pummelo; *P*, winged petiole.

lemon, orange, etc.; sometimes in orange and shaddock, particularly in their early stage, there are three leaflets; this gives support to the palmate nature of the leaf; **bifoliate**, when there are two leaflets so

articulated; **trifoliate**, when three, as in wood-apple and wood-sorrel; **quadrifoliate**, when four, as in *Marsilea* (B. SHUSHNI-SAK); **multifoliate or digitate** (FIGS. 60A-B), when five or more leaflets are so *jointed and spreading like fingers from the palm, as in silk cotton* tree, lupin, *Gynandropsis, Polanisia*, etc.

Note. **Trifoliate Leaves.** Trifoliate leaf of pinnate type can be distinguished from trifoliate leaf of palmate type by the following fact; in the former, as seen in coral tree (*Erythrina*) and country bean (*Dolichos lablab*) the petiole prolongs into a mid-rib (or rachis) and the terminal leaflet is articulated to its apex; *while in the latter all the three leaflets are directly borne* by (or articulated to) the apex of the petiole, as in wood-apple (*Aegle*).

Duration of the Leaf. The *leaf varies in its duration. It may fall off* soon after it appears, and then it is said to be (1) **caducous**; if it lasts one season, *usually falling off in winter, it is* (2) **deciduous or annual**; and if it persists for more than one season, usually lasting a number *of years, it is* (3) ***persistent or evergreen.***

Some Descriptive Terms. (1) **Peltate Leaf.** The leaf-blade and the petiole usually stand in one and the same plane. In some cases, however, as in lotus, water lily, garden nasturtium, etc., the petiole is attached to the centre of the blade at a right angle to it; such a leaf [illegible]
[illegible]
surface, as in most dicotyledons, it is said to be [illegible] back; *venter*, belly or front). *A dorsiventral leaf is more strongly illuminated* on the upper surface than on the lower and, therefore, this *surface is deeper green in colour than the lower. In internal structure* also there is a good deal of difference between the two sides (see FIG. II/64). (3) **Isobilateral Leaf.** When the leaf is directed vertically upwards, as in many monocotyledons, it is said to be isobilateral (*isos*, equal; *bi*, two; *later–*, side). An isobilateral leaf is equally illuminated on both the surfaces and, therefore, the leaf is uniformly green and its internal structure is also uniform from one side to the other (see FIGS. II/65-6). (4) **Centric Leaf.** When the leaf is more or less cylindrical and directed upwards or downwards, as in pine, onion, etc., the leaf is said to be centric. A centric leaf is equally illuminated and, therefore, evenly green on all sides. (5) **Cauline Leaf.** Commonly leaves are directly borne by the aerial part of the stem and the branches; such leaves are said to be cauline (*caulis*, a stem). (6) ***Radical Leaf.*** *In some cases, as in pineapple*, Indian aloe (B. GHRITA-KUMARI; H. GHIKAVAR), century plant or American aloe, many lilies, tuberose, etc., a cluster of *leaves arises from the short* underground stem, as if from the root; such leaves are said to be radical (*radix*, a root). Radical leaves are rather common among monocotyledons. Both radical and cauline leaves may be borne by the same plant, as seen in mustard, radish, etc.

Modifications of Leaves

Leaves of many plants which have to perform specialized functions become modified or metamorphosed into distinct forms. These are as follows:

1. **Leaf-tendrils** (FIGS. 61-2). In some plants leaves are modified into slender, wiry, often closely coiled structures, known as **tendrils**. Tendrils are always climbing organs and are sensitive to contact with a foreign body. Therefore, whenever they come in contact with a neighbouring object they coil round it and help the plant to climb. The leaf may be partially or wholly modified. Thus in pea (FIG. 61A) only the upper leaflets are seen to be modified into tendrils. In traveller's joy (*Naravelia*; FIG. 62) and *Bignonia venusta* (an ornamental climber bearing orange-coloured flowers in huge trusses) it is the terminal leaflet that is converted into a tendril. In glory lily (*Gloriosa*; FIG. 61C) the leaf-apex ends in a closely coiled tendril. In pitcher plant (*Nepenthes*; FIG. 66) the petiole often acts as a tendril holding the

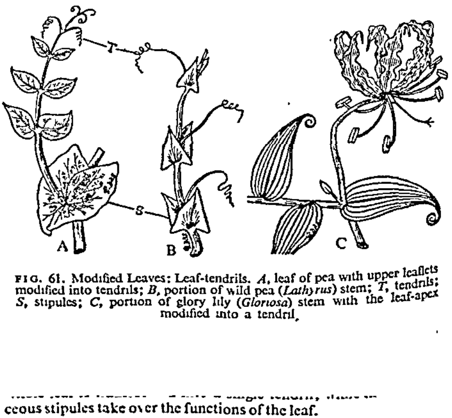


FIG. 61. Modified Leaves: Leaf-tendrils. *A*, leaf of pea with upper leaflets modified into tendrils; *B*, portion of wild pea (*Lathyrus*) stem; *T*, tendrils; *S*, stipules; *C*, portion of glory lily (*Gloriosa*) stem with the leaf-apex modified into a tendril.

ceous stipules take over the functions of the leaf.

Hooks. In *Bignonia unguis-cati* (FIG. 63), an elegant climber, the terminal leaflets become modified into three, very sharp, stiff and curved hooks, very much like

the nails of a cat. These hooks cling to the bark of a tree and act as organs of support for climbing. The plant thus easily climbs to the top of a lofty tree.

FIG. 62. Leaf of *Naravelia* with the terminal leaflet modified into a tendril.

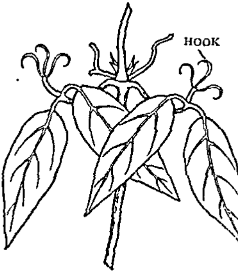


FIG. 63. *Bignonia unguis-cati* with hooks.

2. **Leaf-spines** (FIG. 64). Leaves of certain plants become modified for defensive purposes into sharp, pointed structures, known as spines. That spines are modifications of leaves is evident from the fact that

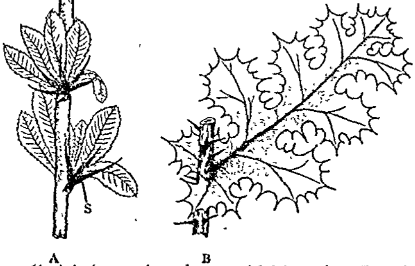


FIG. 64. *A*, barberry; primary leaves modified into spines (*S*); *B*, leaf of prickly poppy (*Argemone*) showing spines.

they occupy the same position as the leaves and that they often bear a bud in their axil, as seen in the flowering shoot of barberry (FIG. 64A).

In prickly pear (*Opuntia*; FIG. 38A) ordinary leaves are feebly developed and s[illegible]
are modified i[illegible]
the leaf itself [illegible]
axillary bud are normal. Spines may also develop at the apex, as in date-palm, dagger plant (see FIG. 78), etc., or on the margin, as in prickly poppy (*Argemone*; B. SHEALKANTA; H. PILA-DHUTURA; FIG. 64B), or in both the places, as in Indian aloe (*Aloe*) and century plant or American aloe (*Agave*).

3. Scale-leaves. Typically these are thin, dry, stalkless, membranous structures, usually brownish in colour or sometimes colourless. Their function is to protect the axillary bud that they bear in their axil. Sometimes scale-leaves are thick and fleshy, as in onion; then their function is to store up water and food. Scale-leaves are common on underground stems, saprophytes, parasites, *Ficus*, *Casuarina* (B. & H. JHAU), *Tamarix* (B. & H. BAN-JHAU), etc.

4. Phyllode (FIG. 65). In Australian *Acacia* the petiole or any part of the rachis becomes flattened or winged taking the shape of the leaf

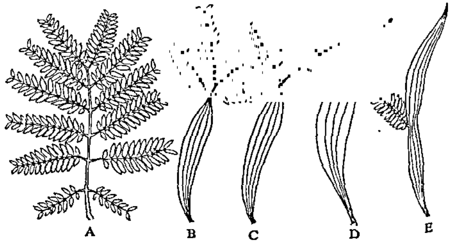
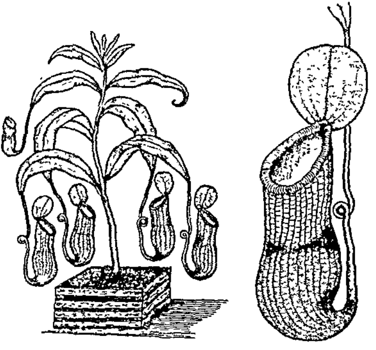


FIG. 65. Development of phyllode in Australian *Acacia*. *A*, pinnately compound leaf; *B-C*, petiole developing into phyllode; *D*, phyllode; and *E*, petiole and rachis developing into phyllode.

[illegible]

vertical direction so that sunlight cannot fall on its surface; this reduces evaporation of water. There are about 300 species of Australian *Acacia*, all showing the phyllode.

5. Pitcher (FIG. 66). In the pitcher plant (*Nepenthes*) the leaf becomes modified into a pitcher. There is a sort of slender stalk which often *coils like a tendril holding the pitcher vertical, and the basal portion* is flattened like a leaf. The pitcher is provided with a lid which



A B

FIG. 66. *A*, pitcher plant (*Nepenthes*); *B*, a pitcher.

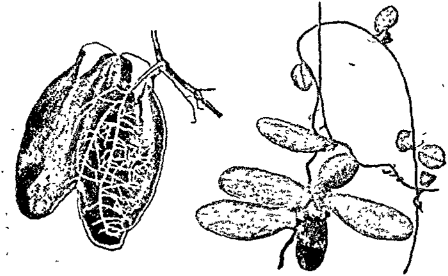


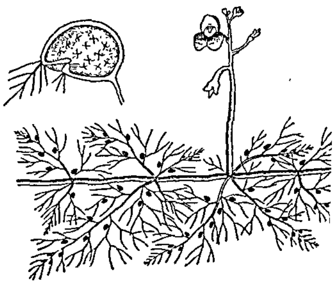
FIG. 67. *Dischidia rafflesiana*; *left*, a pitcher opened out.

covers its mouth when the pitcher is young. The function of th pitcher is to capture and digest insects. The morphology of the lea *of pitcher plant is that the pitcher itself is the* modification of th leaf-blade, the inner side of the pitcher corresponding to the uppe surface of the leaf; the lid arises as an outgrowth of the leaf-ape: The slender stalk, which coils like a tendril, is the petiole. The lam nated structure, which looks like and behaves as the leaf-blade, dev lops from the leaf-base.

Another peculiar modific climbing epiphyte, called pitcher usually varies in size from 5 to 8 cm. in length and 2 to 2½ cm. in It is, however, not carnivorous in nature. As in *Nepenthes*, it has an opening a basal one, but no lid, and instead of this there is a sort of tongue projecting wards. A root enters the cavity of the pitcher and becomes much branche After a shower of rain, water flows down into the pitcher. Prior to this, debris collected there by ants. All this is then absorbed by the root.

6. **Bladder** (FIG. 68). In bladderwort (*Utricularia*), a floating we commonly found in tanks, the leaf is very much segmented. Some

FIG. 68. Bladderwort (*Utricularia*) with many small bladders; *top*, a bladder in section (magnified).



these segments are modified to form bladder-like structures, wit trap-door entrance which allows aquatic animalcules to pass in, never to come out.

Prefoliation. The way in which leaves are arranged in the bud is known as pr llation. This is considered from two standpoints, viz. *first*, the way in which individual leaf is rolled or folded in the bud (ptyxis); and *second*, the wa which the leaves are arranged in the bud with respect to each other (vernati The arrangement of foliage leaves in the vegetative bud and that of the fl leaves in the floral bud are nearly the same, and as such the same terms are to explain the identical types in both cases.

Ptyxis. Rolling or folding of individual leaves may be as follows:

(1) **Reclinate,** when the upper half of the leaf-blade is bent upon the lower half, as in loquat.

(2) **Conduplicate,** when the leaf is folded lengthwise along the mid-rib, as in guava, sweet potato and camel's foot tree (*Bauhinia*, B. KANCHAN; H. KACHNAR).

(3) **Plicate or plaited,** when the leaf is repeatedly folded longitudinally along ribs in a *zigzag* manner, as in fan- or palmyra-palm.

(4) **Circinate,** when the leaf is rolled from the apex towards the base like the tail of a dog, as in ferns.

A B C D E F G

FIG. 69. Ptyxis *A*, reclinate; *B*, conduplicate; *C*, plicate; *D*, circinate; *E*, convolute; *F*, involute; *G*, revolute.

(5) **Convolute,** when the leaf is rolled from one margin to the other, as in banana, aroids and Indian pennywort.

(6) **Involute,** when the two margins are rolled on the upper surface of the leaf towards the mid-rib or the centre of the leaf, as in water lily, lotus, Sandwich Island climber (*Corculum=Antigonon*) and *Plumbago* (B. CHITA; H. CHITRAK).

(7) **Revolute,** when the leaf is similarly rolled on its lower surface, as in oleander and country almond.

(8) **Crumpled,** when the leaf is irregularly folded, as in cabbage.

Phyllotaxy

The term **phyllotaxy** (*phylla*, leaves; *taxis*, arrangement) means the various modes in which the leaves are arranged on the stem or the branch. *The object of this arrangement is to avoid shading one another* so that the leaves may get the maximum amount of sunlight to perform their normal functions (see p. 53), particularly manufacture of food. Three principal types of phyllotaxy are noticed in plants.

(1) **Alternate or Spiral** (FIG. 70A), when a single leaf arises at each node, as in tobacco, China rose, mustard, sunflower, etc.

(2) **Opposite** (FIG. 70B), when two leaves arise at each node standing opposite each other. In opposite phyllotaxy one pair of leaves is *most commonly seen to stand at a right angle to the next upper or lower pair.* Such an arrangement of leaves is said to be opposite decussate or simple decussate. This is seen in sacred basil (*Ocimum*), madar (*Calotropis*), guava, etc. *Sometimes, however, a pair of leaves is seen to stand directly over the lower pair in the same plane.* Such an arrangement of leaves is said to be superposed, as in Rangoon creeper (*Quisqualis*).

(3) **Whorled** (FIG. 70C-D), when there are more than two leaves at each node and these are arranged in a circle or whorl, as in devil

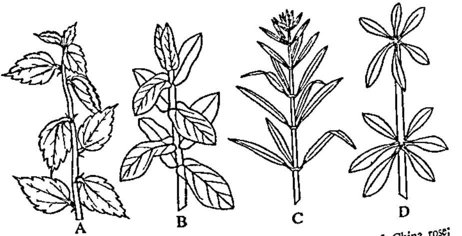


FIG. 70. Types of Phyllotaxy. *A*, alternate phyllotaxy of China rose; *B*, opposite phyllotaxy of madar (*Calotropis*); *C*, whorled phyllotaxy of oleander (*Nerium*); *D*, ditto of devil tree (*Alstonia*).

tree (*Alstonia*), oleander (*Nerium*), *Allamanda*, *Vangueria* (B. MOYENA; H. MOINA), etc. Sometimes both opposite and whorled phyllotaxes may be seen in the same plant.

FIG. 71. Traveller's tree (*Ravenala*) showing distichous phyllotaxy.

Alternate Phyllotaxy. The leaves in this case are seen to be spirally arranged round the stem. Now, if an imaginary spiral line be drawn from the base of one particular leaf, and this line be passed round the stem through the bases of the successive leaves, it is seen that the spiral line finally reaches a leaf which stands vertically over the starting leaf. The imaginary spiral line, thus drawn, is known as the genetic spiral, and the vertical line, i.e. the vertical row of leaves, known as the orthostichy (*orthos*, straight; *stichos*, line).

(1) **Phyllotaxy ½ or 2-ranked or distichous** (FIG. 72). In grasses, bulrush (*Typha*),

traveller's tree (*Ravenala*; FIG. 71), ginger, *Vanda* (see FIG. 13), *Belamcanda*, *Iris*, etc., the *third* leaf stands over the *first*, and the genetic spiral makes *one* complete revolution to come to that leaf, and it involves two leaves (leaving out of consideration the first or the third leaf). The fourth leaf stands over the second, the fifth over the first and the third, and so on. Thus there are only two orthostichies, i.e. leaves are arranged in two rows or ranks. Phyllotaxy is, therefore, 2-ranked or distichous (*di*, two; *stichos*, line). If now the position of the leaves be marked out on a circle or helix, these are seen to be placed at *half the distance of the circle*, leaves being equidistant from each other. The phyllotaxy is said to be half and represented by the fraction $\frac{1}{2}$, the numerator indicating the number *of turns of the genetic spiral*, and the denominator the number of intervening leaves. The genetic spiral makes one complete turn in this case, subtending an angle of 360° in the centre of the circle, and it involves two leaves; so the angular divergence, that is, the angular distance between any two consecutive leaves, is $\frac{1}{2}$ of 360°, i.e. 180°.

(2) **Phyllotaxy $\frac{1}{3}$ or 3-ranked or tristichous** (FIG. 73). In sedges (B. & H. MUTHA) the fourth leaf stands vertically over the first one, and

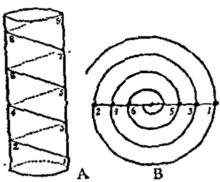


FIG. 72.

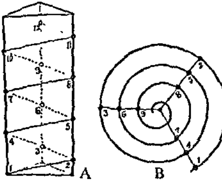


FIG. 73.

FIG. 72. Phyllotaxy and Angular Divergence. *A*, phyllotaxy $\frac{1}{2}$; *B*, angular divergence 180°. FIG. 73. *A*, phyllotaxy $\frac{1}{3}$; *B*, angular divergence 120°.

the genetic spiral makes one complete turn to reach that leaf, and it *involves three leaves. The fifth leaf stands over the second, the sixth* over the third, and the seventh over the fourth and the first. Thus there are three orthostichies, i.e. leaves are arranged in three rows or ranks. If now their position be marked out on a circle or helix, these are seen to be placed at one-third the distance of the circle; so the phyllotaxy is $\frac{1}{3}$ or 3-ranked or tristichous. The angular divergence is $\frac{1}{3}$ of 360°, i.e. 120°.

(3) **Phyllotaxy $\frac{2}{5}$ or 5-ranked or pentastichous** (FIG. 74). In China rose the sixth leaf stands over the first, and the genetic spiral completes *two* circles to come to that particular leaf. The seventh leaf

stands over the second, the eighth over the third, the ninth over the fourth, the tenth over the fifth, and the eleventh over the sixth and the first. Thus there are five orthostichies, i.e. leaves are arranged in five rows, and because two turns of the genetic spiral involve five

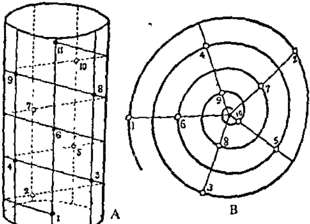


FIG. 74. *A*, phyllotaxy $\frac{2}{5}$; *B*, angular divergence 144°.

leaves, the latter are seen to be placed at two-fifths the distance of the circle. Phyllotaxy is, therefore, $\frac{2}{5}$ or 5-ranked or pentastichous. This is the commonest type of alternate phyllotaxy. The angular divergence in this case is $\frac{2}{5}$ of 360°, i.e. 144°.

[illegible]

met with)

Leaf Mosaic. In the floors, walls and ceilings of many temples and decorated buildings we find setting of stones and glass pieces of variegated colours and sizes into a particular pattern. This pattern is known as mosaic. Similarly, in plants we find that the setting or distribution of leaves is in some definite patterns. Each such pattern of leaf-distribution is known as leaf mosaic. Leaves are in special need of sunlight for manufacture of food material, and this being so, they tend to fit in with one another and adjust themselves in such a way that they may secure the maximum amount of sunlight with the minimum amount of overlapping. Thus in climbers bearing a dense mass of leaves, as in ivy, Indian ivy (see FIG. 16), railway creeper, etc., leaves are disposed in the pattern of a tile-roof. In plants with a rosette of radical leaves or with

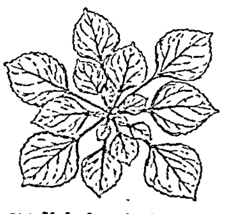


FIG. 75. Leaf mosaic of *Acalypha*.

whorls of leaves it is seen that the upper leaves alternate with the lower ones. In plants with crowded leaves, as in *Acalypha*, *Begonia*, garden nasturtium, etc., these are distributed like the glass-pieces fitting into a mosaic, with the smaller leaves fitting into the interspaces of the broader ones. Crowded leaves of prostrate plants like wood-sorrel, Indian pennywort, etc., also form a more or less perfect mosaic.

Functions of the Leaf. Normal functions of the green leaf are threefold: (1) **manufacture of food** by the chloroplasts in the presence of sunlight out of carbon dioxide and water obtained from the air and the soil respectively; (2) **interchange of gases**—carbon dioxide and oxygen—between the atmosphere and the plant body, the former for manufacture of food by green cells only and the latter for respiration by all the living cells; (3) **evaporation of water**, mainly through the lower surface of the leaf. Besides, certain leaves have some subsidiary functions; for example, storage of water and food by fleshy leaves of *Indian aloe*, *Portulaca*, *etc.*, *fleshy scales of onion*, *lilies*, *Amaryllis*, etc.; vegetative propagation by *Bryophyllum* (see FIG. 15B), *Begonia* (see FIG. 15C), *Kalanchoe* (see FIG. III/57), walking ferns (see FIG. III/54), etc.

Heterophylly. Many plants bear different kinds of leaves on the same individual plant. This condition is known as **heterophylly** (*heteros*, different; *phylla*, leaves). Heterophylly is met with in many aquatic plants, particularly in those growing in running water. Here the float-

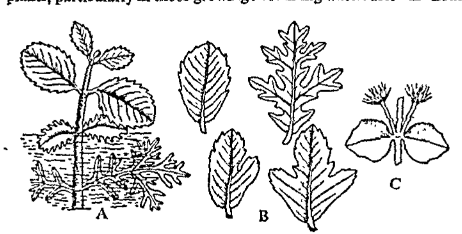


FIG. 76. Heterophylly. *A*, *Cardenthera triflora*; *B*, *Artocarpus chaplasha*; *C*, *Hemiphragma heterophyllum* with needle-like and broad leaves.

ing leaves and the submerged leaves are of different kinds; the former are generally broad, more or less fully expanded, and undivided or merely lobed; while the latter are narrow, ribbon-shaped, linear or much dissected. Heterophylly in water plants is regarded as an adaptation to two different conditions of the environment. Among them water crowfoot (*Ranunculus aquatilis*), *Cardenthera triflora* (FIG. 76A),

etc., show heterophylly, with the submerged leaves much segmented and the floating (or aerial) leaves undivided or merely lobed. In water plantain (*Alisma plantago*) and arrowhead (*Sagittaria*; FIG. 77) submerged leaves are sometimes narrow and ribbon-shaped, while the upper ones are entire or broadly lobed. All transitions of leaf-forms are found in *Limnophila heterophylla*. Some land plants also exhibit this phenomenon without any apparent reason. Among them *Sterculia alata*, *Artocarpus chaplasha* (B. CHAPLASH; FIG. 76B), *Ficus heterophylla* (B. BHUI-DUMUR), etc., show leaves varying from entire to variously lobed structures, and *Hemiphragma heterophyllum* (FIG. 76C),

entire, and those on short axillary branches are needle-shaped.

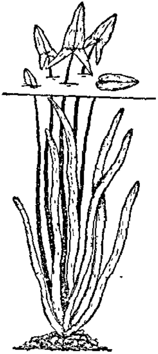


FIG. 77. Arrowhead (*Sagittaria*) showing heterophylly.

Homology and Analogy. Homology is the morphological study of modified organs from the standpoint of their origin, and analogy is the study of organs from the standpoint of their identical structure and function; in other words, organs which resemble one another in their origin, and are, therefore, morphologically the same, whatever be their structure and function, are said to be *homologous* with one another, and organs which resemble one another in their structure and are adapted to the performance of identical functions, although their origin is different, are said to be *analogous* with one another. Thus all tendrils, whatever be their position, are analogous with one another, being structurally the same and performing the same function; but tendrils of passion-flower (see FIG. 35A) are homologous with axillary buds, i.e. modifications of the latter, and tendrils of pea (see FIG. 61A)

they are analogous with the leaves as they have adapted themselves to perform the functions of leaves. So far as the flower is concerned we find that stamens and carpels are homologous with microsporophylls and megasporophylls of gymnosperms and *Selaginella* and with the sporophylls of ferns, and ultimately with vegetative leaves. Similarly sepals and petals are modified vegetative leaves and are homologous with them.

Chapter 4 DEFENSIVE MECHANISMS IN PLANTS

The animal kingdom as a whole is directly or indirectly parasitic upon the plant kingdom, and this being so, plants must either fall a victim to various classes of animals, particularly the herbivorous ones, which live exclusively on a vegetable diet, or they must be provided with special organs or arms of defence, or have other special devices to repulse or avoid the attack of their enemies. Being fixed to the ground they cannot, of course, manœuvre, when attacked by animals.

I. ARMATURE

1. Thorns, Spines, Prickles and Bristles. These are all sharp-pointed, hard structures, specially developed to ward off herbivorous animals. Small spinous plants, commonly called thistles,—globe thistle (*Echinops*), for example,—are beset with numerous spines and prickles all over their body so that no animal dares attack them.

(1) Thorns (see p. 26) are modifications of branches, and originate from deeply-seated tissues of the plant body. They are straight and hard, and can pierce the body of thick-skinned animals. Plants like wood-apple, *Vangueria* (B. MOYENA), lemon, pomegranate, *Duranta*, *Carissa* and many others are well provided with thorns for self-defence.

(2) Spines (see p. 45) are modifications of leaves or parts of leaves, and serve the purpose of defence. These are seen in pineapple, date-palm, prickly poppy, American aloe (*Agave*), dagger plant or Adam's needle (*Yucca*), etc. In dagger plant (*Yucca*; FIG. 78) each leaf ends in a very sharp pointed spine, and is directed outwards.

(3) Prickles are also hard and pointed like the thorns, but are usually curved and have a superficial origin; they are further irregularly distributed on the stem, branch or leaf. Prickles are commonly found in rose, coral tree (*Erythrina*), silk cotton tree (*Bombax*), *Prosopis* (B. & H. SHOMI), etc. Cane (*Calamus*; see FIG. 18A) and

Pisonia (B. BAGH-ANCHRHA), which are large climbing shrubs, are elaborately armed with numerous sharp prickles and spines for self-defence (as well as for climbing).

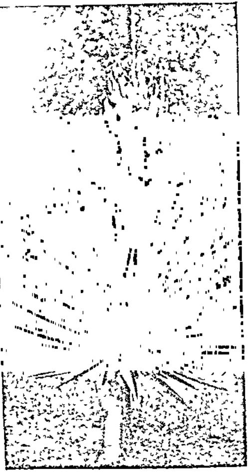


FIG. 78. Dagger plant or Adam's needle (*Yucca*).

(4) **Bristles** are short, stiff and needle-like hairs, usually growing in clusters, and not infrequently barbed. Their walls are often thickened with deposition of silica or calcium carbonate. Bristles are commonly met with in prickly pear (B. PHANI-MANSHA; H. NAGPHANI) and in many other cacti.

2. Stinging Hairs. Nettles (B. BICHUTI; H. BARHANTA) develop stinging hairs on their leaves or fruits or all over their body. Each hair (FIG. 79) has a sharp siliceous apex which breaks off even when touched lightly. The sharp point penetrates into the body, and inflicts a wound into which the acid poison of the hair is forced by the pressure that is suddenly exerted on the swollen base of the hair, causing a sharp burning pain, often attended with inflammation. There are various kinds of nettles, e.g. *Fleurya* (B. LAL-BICHUTI), *Tragia* (B. BICHUTI; H. BARHANTA), fever or devil nettle (*Laportea*), *Girardinia*, cowage (*Mucuna*; B. ALKUSHI; H. KAWANCH), *Urtica dioica*, etc.

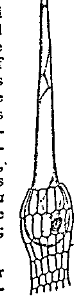


FIG. 79 A stinging hair.

3. Glandular Hairs. Many plants produce glandular hairs on their leaves, branches and fruits. These glandular hairs secrete a sticky substance which is a kind of gum. If any animal feeds upon such a plant the glands stick to its mouth, and the animal finds it

difficult to brush them off. Plants bearing glandular hairs are thus never attacked by grazing animals. Glands of this nature are borne by plants like tobacco, hogweed (*Boerhaavia*), *Jatropha* and *Plumbago*.

4. **Hairs.** A dense coating of hairs or presence of stiff hairs on the body of the plant is always repulsive to animals as these hairs stick on to their throat and cause a choking sensation, e.g. cud-weed (*Gnaphalium*).

II. OTHER DEVICES OF DEFENCE

5. **Poisons.** Many plants secrete poisonous and irritating substances; such plants are carefully avoided by animals which possess the power of distinguishing between poisonous and non-poisonous ones.

(1) **Latex** is the milky juice secreted by certain plants. It always contains some waste products, and often irritating and poisonous substances so that it causes inflammation and even blisters when it comes in contact with the skin. Plants like madar (*Calotropis*), spurges (*Euphorbia*), oleander (*Nerium*), yellow oleander (*Thevetia*), periwinkle (*Vinca*), *Ficus* (e.g. banyan, fig, peepul), etc., contain latex in latex cells; while plants like papaw, poppies, e.g. opium poppy, garden poppy, prickly poppy and some plants of *Compositae*, e.g. *Sonchus*, contain latex in latex vessels.

(2) **Alkaloids** are in many cases extremely poisonous, and a very *minute quantity is sufficient to kill a strong animal*. There are various kinds of them found in plants, e.g. strychnine in nux-vomica, morphine in opium poppy, nicotine in tobacco, daturine in *Datura*, quinine in *Cinchona*, etc.

(3) **Irritating Substance.** Plants like many aroids, e.g. taro (*Colocasia*), *Amorphophallus*, etc., possess needle-like or otherwise sharp and pointed crystals of calcium oxalate, i.e. raphides. These crystals, when such plants are fed upon, prick the tongue and the throat and cause irritation. Therefore, such plants never fall victims to the attack of grazing animals.

6. **Bitter Taste and Repulsive Smell.** These are also effective mechanisms to ward off animals. *Paederia foetida* emits a bad smell so *that no animal likes to go near it. Plants like sacred basil, mint, Blumea lacera, Gynandropsis*, etc., also emit a strong disagreeable odour. The fetid smell of the inflorescence of *Amorphophallus* (see FIG. 134) is very offensive and nauseating. Margosa, bitter gourd, *Andrographis*, etc., have a bitter taste and are avoided by animals.

7. **Waste Products.** Apart from latex, alkaloids, etc., mentioned above, the presence of many other waste products such as tannin, resin, essential oils, raphides and silica also keep plants free from the attack of animals.

8. **Mimicry.** Certain plants also protect themselves against grazing animals by imitating the general appearance, colour, shape or particular feature of another plant or animal, which has developed a special weapon of defence; for instance, there are certain aroids (e.g. varieties of *Caladium*) which resemble multi-coloured and variously spotted snakes. Leaves are also variously spotted and striped in many species of bow-string hemp (*Sansevieria*; B. MURGA; H. MARUL) and other allied plants. Herbivorous animals, possibly mistaking them for snakes or some other deadly creatures, carefully avoid them. The inflorescences of devil's spittoon (*Amorphophallus bulbifer*; B. BAN-OL) coming out of the ground look like hoods of snakes, at least from a distance. In another aroid, called snake plant (*Arisaema*; FIG. 80), common in Shillong and Darjeeling during the rains, the spathe is greenish-purple in colour and it expands over the spadix like the hood of the cobra. This act of imitating the appearance, colour or any particular feature of another plant or animal, is called **mimicry** (*mimikos*, imitative).

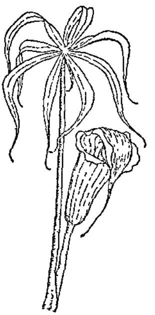


FIG. 80. Snake or cobra plant (*Arisaema*).

Plants have also to protect themselves against the attack of many parasitic fungi and gnawing insects, and also against the scorching rays of the sun; this they do by developing thick cuticle, cork and bark.

Chapter 5 THE INFLORESCENCE

The reproductive shoot bearing commonly a number of flowers, or sometimes only a single flower, is called the **inflorescence**. It may be terminal or axillary, and may be branched in various ways. Thus depending on the mode of branching different kinds of inflorescence have come into existence, and these may primarily be classified into two distinct groups, viz. racemose or indefinite and cymose or definite.

Origin. It is not possible to trace the origin and phyllogeny of inflorescence from the primitive to the recent type. This is particularly so because our knowledge regarding the phyllogeny of angiosperms is still insufficient. The speculation in this regard is based on the following considerations, and three theories have

called the pedicel. In the case of the solitary flower its stalk is regarded and termed as the peduncle. In some flowers such as China rose, gold mohur, etc., the peduncle and the pedicel may, however, be clearly marked out due to the

FIG. 81. Racemose Inflorescences. *A*, raceme of dwarf gold mohur; *B*, spike (diagrammatic); *C*, spikelet of a grass (diagrammatic); G_1, first empty glume; G_2, second empty glume; *FG*, flowering glume or lemma; and *P*, palea; *D*, female catkin of mulberry.

presence of an articulation on the floral axis. When the peduncle of an inflorescence is short and dilated forming a sort of convex platform, as in sunflower, or becoming hollow and pear-shaped, as in fig (*Ficus*), it is often called the receptacle. The unbranched, often leafless, peduncle arising out of the underground stem in the midst of radical leaves and ending in a single flower, as in lotus, or in an inflorescence, as in onion, tuberose, etc., is known as the scape (see also p. 10).

(2) Spike (FIG. 81B). Here also the main axis is elongated and the lower flowers are older, opening earlier than the upper ones, as in raceme, but the flowers are sessile, that is, without any stalk. Examples are seen in tuberose, *Adhatoda* (B. BASAK; H. ADALSA), ama-

spikelet bears at its base two minute scales or bracts called *empty glumes*; slightly higher up it bears a third bract called *flowering*

of the grass family, e.g. grasses, paddy, wheat, sugarcane, bamboo, etc.

(4) Catkin (FIG. 81D). This is a spike with a long and pendulous axis which bears unisexual flowers only, e.g. mulberry (*Morus*), *Acalypha densiflora*, birch (*Betula*) and oak (*Quercus*).

(5) Spadix (FIG. 82). This is also a spike with a fleshy axis, which is enclosed by one or more large, often brightly coloured bracts, called spathes, as in aroids, banana and palms. The spadix is found in monocotyledons only.

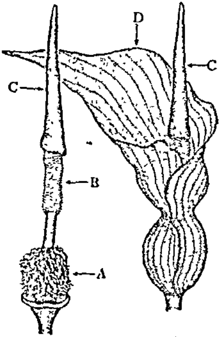


FIG. 82. Spadix of an aroid (*Typhonium*); *A*, female flowers; *B*, male flowers; *C*, appendix; and *D*, spathe.

B. *WITH THE MAIN AXIS SHORTENED*

(6) Corymb (FIG. 83A). Here the main axis is comparatively short, and the lower flowers have much longer stalks or pedicels than the upper ones so that all the flowers are brought more or less to the same level, as in candytuft (*Iberis*) and wallflower.

(7) Umbel (FIG. 83 B-C). Here the primary axis is shortened, and it bears at its tip a group of flowers which have pedicels of more or

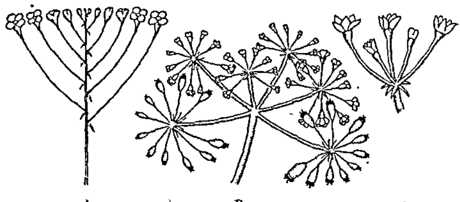


FIG. 83. *A*, corymb (diagrammatic); *B*, a compound umbel; *C*, a simple umbel.

less equal lengths so that the flowers are seen to spread out from a common point. In the umbel there is always a whorl of bracts forming an involucre, and each flower develops from the axil of a bract.

Commonly the umbel is branched (**compound umbel**) and the branches bear the flowers, as in anise or fennel, coriander, cumin, carrot, etc. Sometimes, however, it is simple or unbranched (**simple umbel**), the main [illegible]
and wild [illegible]
family or [illegible]

C. WITH THE MAIN AXIS FLATTENED

(8) **Head or Capitulum** (FIG. 84). Here the main axis or receptacle is suppressed, becoming almost flat, and the flowers (florets) are also without any stalk so that they become crowded together on the flat surface of the receptacle. In it the outer flowers are older and open earlier than the inner ones. Although the whole inflorescence looks like a single flower, it really consists of a clustered mass of small sessile flowers (florets) usually of two kinds—**ray florets** (marginal strap-shaped ones) and **disc florets** (central tubular ones). The head may also consist of only one kind of florets. The inflorescence is surrounded at the base by one or more whorls of often green bracts forming an *involucre* (see p. 70). A head or capitulum is characteristic of sunflower family or *Compositae* (e.g. sunflower, marigold, safflower, *Zinnia*, *Cosmos*, *Tridax*, etc.). It is also found in gum tree (*Acacia*), sensitive plant (*Mimosa*), *Anthocephalus* (B. & H. KADAM), *Adina* (B. & H. KELI-KADAM), etc.

Capitulum is regarded as the most perfect type of inflorescence. Although the individual florets are often very small, their mass effect is not negligible at all. As a matter of fact a head with often a few dozens of florets clustered together in it becomes quite conspicuous

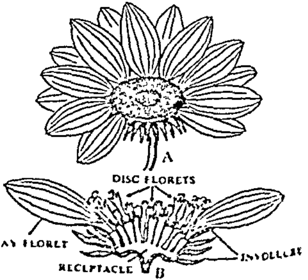


FIG. 84. Head or capitulum. *A*, a head (a few ray florets removed to show the involucre); *B*, a head in longitudinal section.

and attractive. The advantages of such an inflorescence are that there is a considerable saving of material in the construction of the corolla and other floral parts and that a single insect can easily pollinate innumerable florets within a very short time without having to fly from one flower to another. The ultimate advantage is that this mass pollination helps the setting of seeds in most heads for reproduction, multiplication in number and continuity of species.

2. **Cymose Inflorescences.** Here the growth of the main axis is soon checked by the development of a flower at its apex, and the lateral axis which develops below the terminal flower also ends in a flower and, therefore, its growth is also checked. The flowers may be with or without stalks. In the cymose inflorescence the flowers develop in *basipetal* succession, i.e. the terminal flower is the oldest and the lateral ones younger, or, in other words, the order of opening of the flowers is *centrifugal.* Cymose inflorescence may be uniparous, biparous or multiparous.

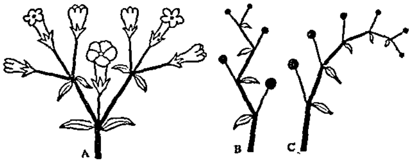


FIG. 85. Cymose Inflorescences. *A*, biparous cyme; *B*, scorpioid cyme; *C*, helicoid cyme.

(1) **Uniparous or Monochasial Cyme** (*unus*, one; *parere*, to produce). In this type of inflorescence the main axis ends in a flower and it produces only one lateral branch at a time ending in a flower. The lateral and succeeding branches again produce only one branch at a time like the primary one. Two forms of uniparous cyme may be seen—helicoid and scorpioid. (*a*) When the lateral axes develop successively on the same side, evidently forming a sort of helix, as in *Begonia*, rush (*Juncus*), many plants of potato family or *Solanaceae*, day lily (*Hemerocallis*), etc., the cymose inflorescence is said to be a helicoid (or one-sided) cyme (FIG. 85C). (*b*) On the other hand when the lateral branches develop on alternate sides, evidently forming a zig-zag, as in cotton, sundew, heliotrope (B. HATISUR; H. HATTASURA) and *Freesia*, the cymose inflorescence is said to be a scorpioid (or alternate-sided) cyme (FIG. 85 B).

In *monochasial* cyme successive axes may be at first [illegible] curved, but subsequently become straightened out due to their [illegible]

growth thus forming the so-called central axis, otherwise known as *pseudo-axis*. This type of inflorescence is called a sympodial cyme. This may be distinguished from the racemose type by examining the position of a bract to a flower; in a sympodial cyme a bract appears opposite to a flower, while in a racemose type a bract appears at the base of a flower.

(2) **Biparous or Dichasial Cyme** (*bi*, two; *parere*, to produce). In this type of inflorescence the main axis ends in a flower and at the same time it produces two lateral younger flowers or two lateral branches. The lateral and succeeding branches in their turn behave in the same manner (FIG. 85A). This is true cyme. Examples are seen in pink, jasmine, teak, night jasmine, *Ixora*, glory of the garden, etc.

(3) **Multiparous or Polychasial Cyme.** In this kind of cymose inflorescence the main axis, as usual, ends in a flower, and at the same time it again produces a number of lateral flowers around. There being a number of lateral flowers developing more or less simultaneously, the whole inflorescence looks like an umbel, but is readily distinguished from the latter by the opening of the middle flower first. This is seen in madar (*Calotropis*) and *Hamelia patens*.

Compound and Mixed Forms. When the main axis of the inflorescence is branched and the branches bear the flowers, the inflorescence is said to be compound; as, for example, when raceme is branched it is called a compound raceme or panicle (FIG. 86), as in gold mohur (B. KRISHNACHURA), margosa (B. & H. NIM), dagger plant, etc. Similarly, other compound forms are also present such as compound spike, as in wheat; compound spadix, as in palms; compound corymb, as in candytuft; compound umbel, as in coriander and anise; and compound head, as in globe thistle (*Echinops*). Quite frequently mixed inflorescences can be found.

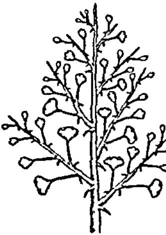


FIG. 86. A panicle.

3. **Special Types.** The following types may be noted.

(1) **Cyathium** (FIG. 87). This is a special kind of inflorescence found in *Euphorbia*, e.g. poinsettia (B. & H. LAL-PATA) and spurges (B. & H. SIJ), and also in jew's slipper (*Pedilanthus*; B. RANG-CHITA; H. NAGDAMAN). In cyathium there is a cup-shaped involucre, often provided with nectar-secreting glands. The involucre encloses a single female flower (reduced to a pistil) in the centre, seated on a comparatively long stalk, and a number of male flowers (each reduced to a solitary stamen) around this, seated on short stalks. That each

stamen is a single male flower is evident from the facts that it is articulated to a stalk and that it has a scaly bract at the base. The

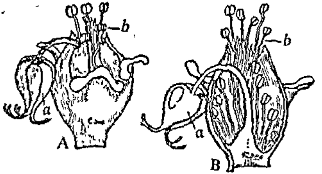


FIG. 87. Cyathium of poinsettia. *A*, cyathium; *B*, the same in longitudinal section; (*a*) female flower; (*b*) male flower. Note the involucre.

flowers follow the centrifugal (cymose) order of development. The *female flower in the centre matures first, and then the stamens (male flowers) just surrounding it, and ultimately the marginal ones.*

(2) **Verticillaster** (FIG. 88). This is a condensed form of cymose inflorescence with a cluster of sessile or almost sessile flowers in the

FIG. 88. Verticillaster of *Coleus*. *A*, verticillaster; *B*, diagram of verticillaster.

axil of a leaf, forming a false whorl at the node. The first axis gives rise to two lateral branches and these branches and the succeeding ones bear only one branch each on alternate sides. This kind of inflorescence is found in several members of basil family or *Labiatae*, e.g. *Coleus*, *Leonurus*, *Leucas*, etc. In sacred basil (B. & H. TULSI), sage (*Salvia*) and a few others the verticillaster is reduced to a dichasial cyme, succeeding branches remaining undeveloped.

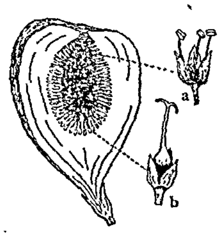


FIG. 89. Hypanthodium of fig (*Ficus*). *a*, male flower; *b*, female flower.

(3) **Hypanthodium** (FIG. 89). When the fleshy receptacle forms a hollow cavity, more or less pear-shaped, with a narrow apical opening guarded by scales, and the flowers are borne on the

inner wall of the cavity, the inflorescence is a hypanthodium, as in *Ficus* (e.g. banyan, fig, peepul, etc.). Here the female flowers develop at the base of the cavity and the male flowers higher up towards its mouth.

Chapter 6 THE FLOWER

The flower is a metamorphosed shoot meant essentially for the reproduction of the plant. A typical or complete flower consists of two

... are sepals, of corolla petals, of androecium ... sporophylls, and of gynoecium **carpels** or megasporophylls. The term **perianth** is collectively used for undifferentiated calyx and corolla and its members are called **tepals**. The four whorls develop in an ascending order from the swollen suppressed end (**thalamus**) of the floral axis or stalk (**pedicel**). Androecium is the male whorl and each stamen of it is differentiated into **filament**, **anther** and **connective**. Gynoecium or pistil is the female whorl differentiated into **ovary**, **style** and **stigma**.

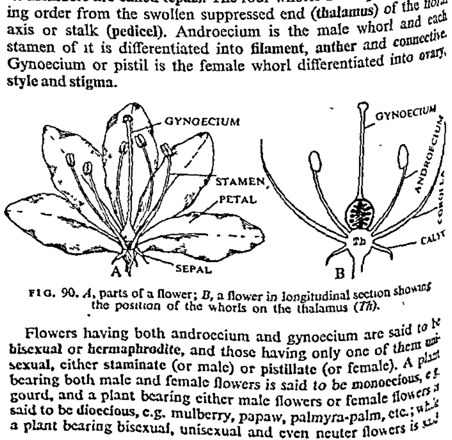


FIG. 90. *A*, parts of a flower; *B*, a flower in longitudinal section showing the position of the whorls on the thalamus (*Th*).

Flowers having both androecium and gynoecium are said to be **bisexual** or **hermaphrodite**, and those having only one of them **unisexual**, either **staminate** (or male) or **pistillate** (or female). A plant bearing both male and female flowers is said to be **monoecious**, e.g. gourd, and a plant bearing either male flowers or female flowers is said to be **dioecious**, e.g. mulberry, papaw, palmyra-palm, etc.; while a plant bearing bisexual, unisexual and even neuter flowers is said

to be polygamous, e.g. *Polygonum*, mango and wild mangosteen (B. GAB; H. KENDU). Further it may be noted that a flower without calyx and corolla is said to be naked or achlamydeous, as in betel; a flower with only one whorl monochlamydeous, as in *Polygonum*; and a flower with both the whorls dichlamydeous.

The flower is said to be cyclic when sepals, petals, stamens and carpels are arranged in circles or whorls round the thalamus, as in most flowers, and acyclic when these are spirally arranged, as in water lily, *Magnolia* (B. DULEE-CHAMPA), *Michelia* (B. CHAMPA; H. CHAMPAK), etc. The flower may be hemicyclic also when some parts are cyclic and others acyclic, as in rose.

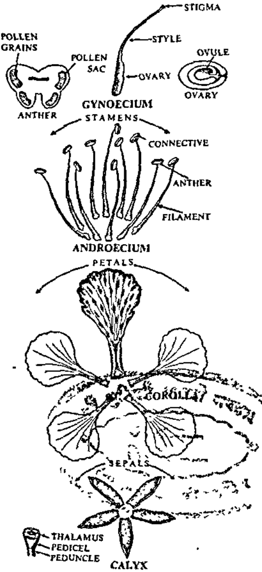


FIG. 91. Flower of gold mohur (*Delonix regia*) dissected out.

Thalamus. The thalamus (see FIG. 90B), also called torus or receptacle, is the suppressed swollen end of the flower-axis on which are inserted the floral leaves, viz. the sepals, petals, stamens and carpels. In most flowers this thalamus is very short; but in a few cases it becomes elongated, and then it shows distinct nodes and internodes. Thus the internode between the calyx and the corolla, when elongated, is known as the **anthophore** (*anthos*, a flower; *phore*, a stalk), as in *Silene* (a genus of pink family). In *Gynandropsis* (FIG. 92A) and passion-flower (FIG. 92B) the internode between the corolla and the androecium is considerably elongated, and is known as the **androphore** (*andros*, male) or gonophore. In *Capparis* (FIG. 93A), *Gynandropsis* (FIG. 92A), *Pterospermum* (B. MOOCHKANDA; H. KANAKCHAMPA—FIG. 92C), drumstick (B. SAJINA; H. SAINJNA), etc., the axis between the androecium and the gynoecium is elongated, and is known as the **gynophore** (*gyne*, female). When both

androphore and gynophore develop they are together known as the androgynophore, as in *Gynandropsis*. In *Magnolia* and *Michelia* the

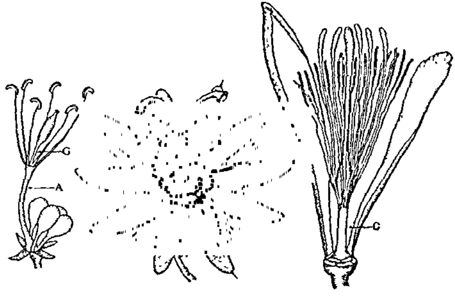


FIG. 92. Thalamus. A, flower of *Gynandropsis*; *A*, androphore; *G*, gynophore; B, passion-flower; *A*, androphore; C, flower of *Pterospermum*; *G*, gynophore (with the staminal tube adnate to it).

thalamus is fleshy and elongated, and bears the floral leaves spirally round it. In rose (FIG. 93B) it is concave and pear-shaped. The thalamus of lotus (FIG. 93C) is spongy and top-shaped. When the thalamus

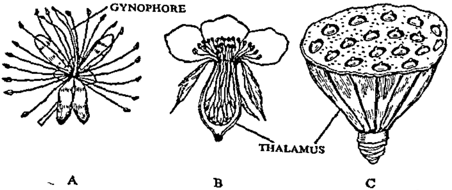


FIG. 93. Thalamus (*contd.*). *A*, flower of *Capparis*; *B*, rose (in section); *C*, lotus.

becomes prolonged upwards into a slender axis with the carpels remaining attached to it at first and separating from it on maturity the axis is called carpophore, as in balsam (*Impatiens*), anise (FIG. 94), coriander, cumin, *Geranium*, etc.

Position of Floral Leaves on the Thalamus. Normally the calyx, corolla, androecium and gynoecium of a flower lie on the thalamus in their proper sequence. But in many flowers *the relative positions of the first three whorls* in respect of the ovary become disturbed due to the unusual growth of the thalamus. The relative positions, as seen in the flowers of different plants, are of three kinds, viz., hypogyny, perigyny and epigyny (FIGS. 95-7).

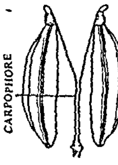


FIG. 94. Fruit of anise.

(1) **Hypogyny.** In a hypogynous flower the thalamus *is conical, convex, flat or slightly* concave, and the ovary occupies the highest position on the thalamus; while the stamens, petals and sepals are separately and successively inserted below the ovary. The ovary is said to be *superior* and the rest of the floral members *inferior*. Examples are seen in mustard, brinjal, China rose, *Magnolia*, etc.

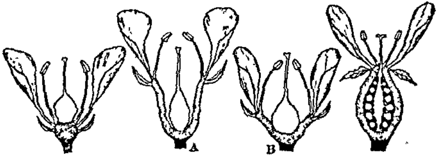


FIG. 95 FIG. 96 FIG. 97

Position of Floral Leaves on the Thalamus. FIG. 95. Hypogyny. FIG. 96. Perigyny (two types—A & B). FIG. 97. Epigyny.

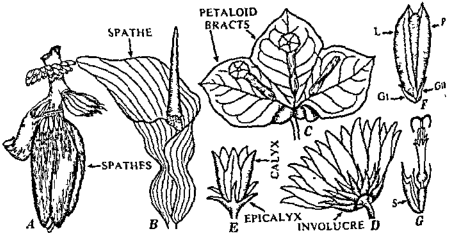
(2) **Perigyny.** In a perigynous flower the margin of the thalamus grows upward to form a cup-shaped structure, called the calyx-tube, *enclosing the ovary but remaining free from it, and carrying with it* the sepals, petals and stamens. The ovary is said to be *half-inferior*. In some perigynous flowers the ovary may be partially sunken in the thalamus. Examples are seen in rose, plum, primrose, peach, prune, crepe flower and sometimes in *Leguminosae* (e.g. pea, bean, gold mohur, etc.).

(3) **Epigyny.** In an epigynous flower the margin of the thalamus grows further upward, completely enclosing the ovary and getting fused with it, and bears the sepals, petals and stamens above the ovary. The ovary in this case is said to be *inferior*, and the rest of the floral members *superior*. Examples are seen in sunflower, guava, gourd, cucumber, apple, pear, etc.

Bracts (FIG. 98). Bracts are special leaves from the axil of which one or more flowers arise. When a small leafy or scaly structure is present on the flower-stalk (pedicel) in any part of it, it goes by the name of bracteole. Bracts vary in shape, size, colour and duration. They may be of the following kinds.

(1) **Foliaceous (or Leafy) Bracts.** These are green, flat and leaf-like in appearance, as in *Adhatoda*, *Acalypha*, *Gynandropsis*, etc.

(2) **Spathe** (A-B). This is a large, sometimes very large, and commonly boat-shaped bract enclosing a cluster of flowers or even an inflorescence (spadix), as in banana, aroids, palms, maize cob, etc.



(3) **Petaloid Bracts** (C). These are brightly coloured bracts looking somewhat like petals, as in glory of the garden. In poinsettia the petaloid bracts, red in colour, take the shape of leaves.

(4) **Involucre** (D). This is one or more whorls of bracts, normally green in colour, present around a cluster of flowers. Involucre is characteristic of *Compositae*, e.g. sunflower, marigold, *Cosmos*, etc. It is also present in *Umbelliferae*, e.g. coriander, anise, carrot, etc.

(5) **Epicalyx** (E). This is one or more whorls of bracteoles developing at the base of the calyx. Epicalyx is characteristic of *Malvaceae*, e.g. China rose, cotton, lady's finger, etc. Epicalyx is also present in many plants of rose family or *Rosaceae*, e.g. strawberry.

(6) **Scaly Bracteole** (G). At the base of the individual florets of head or capitulum of *Compositae* there is often a thin, membranous, awl-shaped scaly bracteole.

(7) **Glumes** (F). These are special bracts—small, dry and scaly—found in the spikelet of grass family. The bracts take the form of two

minute scales called *empty glumes* at the base, a flowering glume called *lemma*, and a bracteole called *palea* (see also p. 60).

Flower is a Modified Shoot. The following facts may be cited to prove that the *thalamus* is a modified branch; *sepals, petals, stamens* and *carpels* are modified vegetative leaves; and the *flower* as a whole a modified vegetative bud.

(1) The thalamus represents the axis of the floral whorls with internodes between them normally remaining undeveloped or suppressed; but in some flowers the thalamus becomes elongated showing distinct nodes and internodes (see FIGS. 92-4), as in *Gynandropsis*, passion-flower, *Capparis*, *Pterospermum*, etc. The thalamus may, therefore, be regarded as a modified branch.

(2) The thalamus sometimes shows monstrous development, i.e. after bearing the floral members it prolongs upwards and bears ordinary foliage leaves. The thalamus thus behaves as a branch. Examples are sometimes seen in rose (FIG. 99), larkspur, pear, etc.

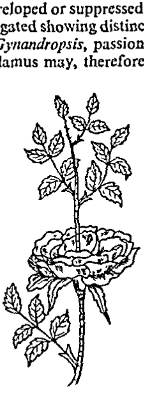


FIG. 99. Rose showing monstrous development of the thalamus.

(3) The foliar nature of sepals is evident from their similarity to leaves as regards structure, form and venation; in fact, in *Mussaenda* (FIG. 100) one of the sepals becomes modified into a distinct white or coloured leafy structure. The origin of petals is controversial. Some are of opinion that the petals are related to the sepals, while others consider the petals to have been derived from stamens. In green rose the petals are leaf-like in structure and green in colour. But stamens and carpels are unlike leaves in all respects.[1] The homology of stamens and carpels with leaves can also be made out from certain flowers. Thus water lily (FIGS. 101-2) shows a gradual transition from sepals to petals and from petals to stamens. The cultivated rose shows many petals; while in wild rose there are only five. The explanation is that many stamens have gradually become modified

[1] The foliar nature of the stamen is explained by the way that it is formed by the inrolling of the margins of the lamina towards the mid-rib, having two parts (filament representing the mid-rib, and the anther the lamina) according to some; three parts including the connective according to others. The foliar nature of the carpel may be made out from certain flowers; for example, in pea (see FIG. 123) the carpel folds to form the ovary, but when opened by the ventral suture it looks like a leaf. This view was first expressed by De Candolle, a French systematist, in 1827.

into petals. Similarly, in certain varieties of China rose and in *Hibiscus mutabilis* (B. STHAL-PADMA; H. GULIAJAIB) some or many of the stamens have passed into petals.

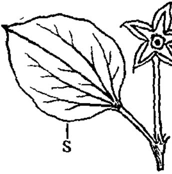


FIG. 100

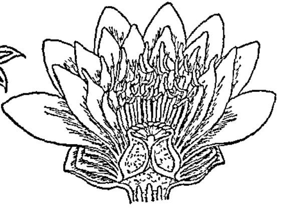


FIG. 101

FIG. 100. *Mussaenda* flower showing a modified (petaloid and leaf-like) sepal (*S*).
FIG. 101. Water lily flower showing transition of floral parts.

(4) A floral bud like a vegetative bud is either terminal or axillary in position. The arrangement of sepals, petals, etc., on the thalamus is much the same as that of the leaves on the stem or the branch, being either whorled, alternate (spiral) or opposite.

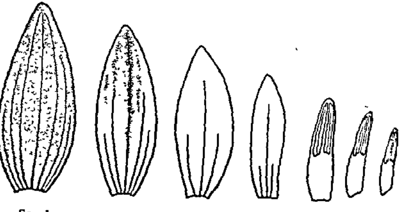


FIG. 102. Transition of floral parts in water lily flower.

... thus show a reversion to ancestral forms, i.e. the forms from which they have been derived.

Symmetry of the Flower. A flower is said to be symmetrical when it can be divided into two exactly equal halves by *any* vertical section passing through the centre. Such a flower is also said to be regular or actinomorphic or radially symmetrical. Examples are found in mustard, *Datura*, brinjal, chilli, etc. When a flower can be divided into two similar halves by *one* such vertical section only, it is said to be zygomorphic or monosymmetrical or bilaterally symmetrical, as in pea, bean, rattlewort (B. ATASHI; H. JHUNJHUNIA), gold mohur, *Cassia*, etc., and when it cannot be divided into two similar halves by any vertical plane whatsoever, it is said to be asymmetrical or irregular.

A flower is also said to be symmetrical when its whorls have an equal number of parts or when the number in one whorl is a multiple of that of another. Such a symmetrical flower is said to be isomerous (*isos*, equal; *meros*, a part). An isomerous flower may be *bimerous*, *trimerous*, *tetramerous* or *pentamerous*, according as the number of parts in each whorl is 2, 3, 4 or 5 or any multiple of it. Carpels, however, often do not fit into this symmetry and may, therefore, be ignored. Trimerous flowers are common among monocotyledons, and pentamerous flowers among dicotyledons. When the number in all the whorls is neither the same nor any multiple, the flower is said to be heteromerous (*heteros*, different).

(1) Calyx

Calyx is usually green (*sepaloid*), sometimes coloured otherwise (*petaloid*). In its symmetry the calyx may be regular, zygomorphic or irregular. It may again be polysepalous (sepals free) or gamosepalous (sepals united). Calyx is often modified into pappus, as in *Compositae*. In *Mussaenda* (see FIG. 100) one of the sepals becomes distinctly leafy, large, white or coloured.

Duration. If the calyx falls off as soon as the floral bud opens it is said to be caducous, as in poppy. The calyx is said to be deciduous if it falls off when the flower withers. But sometimes it remains adherent to the fruit; then it is known as persistent. A persistent calyx may assume a withered appearance, as in cotton, or it may continue to grow and form a sort of cup at the base of the fruit, as in brinjal, or it may be inflated enclosing the fruit, as in balloon vine (see FIG. 36), gooseberry and wild gooseberry, or it may be quite fleshy, as in *Dillenia* (B. & H. CHALTA), or it may be fleshy and coloured forming the outer envelope of the fruit, as in *Duranta*.

(2) Corolla

Corolla may also be regular or radially symmetrical, zygomorphic or

bilaterally symmetrical, or **irregular** (see p. 73). Like the calyx again, the corolla may be **gamopetalous** or **polypetalous**, according as the petals are united or free. In the former case the petals may be united partially or wholly.

Forms of Corollas

I. REGULAR AND POLYPETALOUS

(1) **Cruciform** (FIG. 103A). The cruciform corolla consists of four free petals, each differentiated into a claw and a limb, and these are arranged in the form of a cross, as in *Cruciferae*, e.g. mustard, radish, cabbage, cauliflower, candytuft, etc.

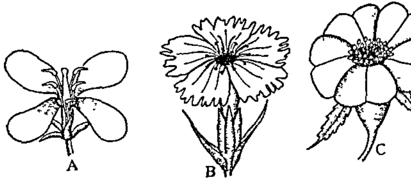


FIG. 103. Forms of Corollas. *A*, cruciform; *B*, caryophyllaceous; *C*, rosaceous.

(2) **Caryophyllaceous** (FIG. 103B). This form of corolla consists of five petals with comparatively long claws, and the limbs of the petals are placed at right angles to the claws, as in pink (*Dianthus*).

(3) **Rosaceous** (FIG. 103C). This form consists of five petals, as in the previous case, but these have very short claws or none at all, and the limbs spread regularly outwards, as in rose, tea, prune, *etc.*

II. REGULAR AND GAMOPETALOUS

(1) **Campanulate or Bell-shaped** (FIG. 104A). When the shape of the corolla resembles that of a bell, as in gooseberry, bell flower (*Campanula*), wild mangosteen (B. GAB; H. KENDU), etc., it is said to be campanulate.

(2) **Tubular** (FIG. 104B). When the corolla is cylindrical or tube-like, that is, more or less equally expanded from base to apex, as in the central florets of sunflower, it is said to be tubular.

(3) **Infundibuliform or Funnel-shaped** (FIG. 104C). When the corolla is shaped like a funnel, that is, gradually spreading outwards from a narrow base, as in thorn-apple (*Datura*), water bindweed (B. & H. KALMI-SAK), railway creeper, morning glory, etc., it is said to be infundibuliform.

(4) Rotate or Wheel-shaped (FIG. 104D). When the tube of the corolla is narrow, short or long, and the limb of it is at a right angle

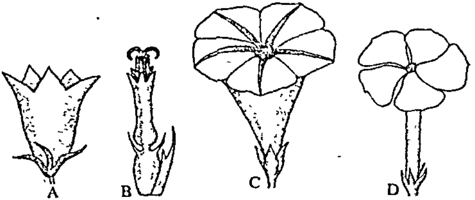


FIG. 104. Forms of Corollas (*contd.*). *A*, campanulate; *B*, tubular; *C*, funnel-shaped; *D*, rotate.

to the tube, the corolla having more or less the appearance of a wheel, as in jasmine, night jasmine, periwinkle, *Ixora*, etc., it is said to be rotate.

III. ZYGOMORPHIC AND POLYPETALOUS

(1) Papilionaceous or Butterfly-like (FIG. 105A). The general appearance is like that of a butterfly. It is composed of five petals, of which

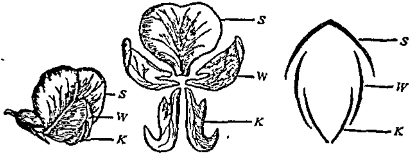


FIG. 105. *A*, papilionaceous flower of pea. *B*, petals of the same opened out; *C*, vexillary aestivation of papilionaceous corolla; *S*, standard or vexillum; *W*, wing; *K*, keel.

the outermost one is the largest and known as the standard or vexillum, the two lateral ones, partially covered by the former, are somewhat like the two wings of a butterfly and known as the wings or alae, and the two innermost ones, apparently united to form a boat-shaped cavity, are the smallest and are together known as the keel or carina. Examples are found in *Papilionaceae*, e.g. pea, bean, gram, butterfly pea (*Clitoria*), rattlewort (*Crotalaria*), etc.

IV. ZYGOMORPHIC AND GAMOPETALOUS

(1) **Bilabiate or Two-lipped** (FIG. 106A). In this form the limb of the corolla is divided into two portions or lips—the upper and the lower, with the mouth gaping wide open. Examples are seen in sacred basil (*Ocimum*), *Leonurus* (see FIG. VII/53), *Leucas*, *Hygrophila*, *Adhatoda*, etc.

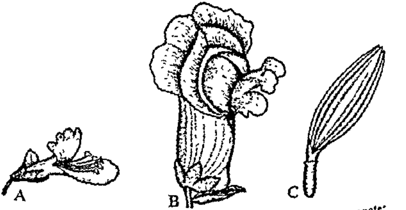


FIG. 106. Forms of Corollas (*contd.*). *A*, bilabiate; *B*, personate; *C*, ligulate.

(2) **Personate or Masked** (FIG. 106B). This is also two-lipped like the previous one, but in this case the lips are placed so near to each other as to close the mouth of the corolla. The projection of the lower lip closing the mouth of the corolla is known as the *palate*, as in snapdragon, *Lindenbergia*, etc.

(3) **Ligulate or Strap-shaped** (FIG. 106C). When the corolla forms into a short, narrow tube below, but is flattened above like a strap, as in the outer florets of sunflower, it is said to be ligulate.

Appendages of the Corolla. The corolla or the perianth is sometimes provided with outgrowths or appendages of various kinds; as, for

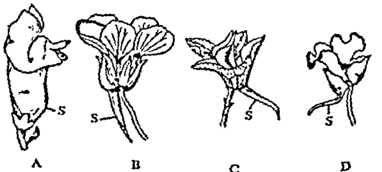


FIG. 107. Appendages of Perianth. *A*, saccate corolla (*S*) of snapdragon; *B*, flower of garden nasturtium; *C*, flower of larkspur; *D*, flower of balsam; *S*, spur.

instance, in snapdragon the tube of the corolla is slightly dilated on one side like a pouch or sac; it is then said to be saccate or gibbous (FIG. 107A). In some cases, as in balsam, garden nasturtium and larkspur, the perianth is prolonged into a tube, known as the spur (FIGS. 107 B-D), and it (the perianth) is then said to be spurred. In some flowers a special sac, known as the nectary, develops containing nectar.

Sometimes, by a transverse splitting of the corolla, an additional whorl may be formed at its throat. This additional whorl may be made up of lobes, scales or hairs, free or united, and is known as the corona (*crown*). The corona may be well seen in passion-flower (FIG. 108A), dodder (FIG. 108B), and oleander (FIG. 108C). A beautiful,

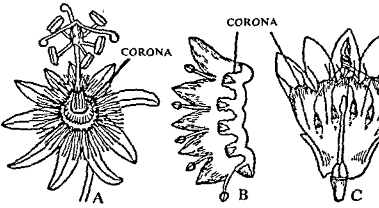


FIG. 108. Appendages of Corolla: Corona. *A*, passion-flower; *B*, flower of dodder; *C*, flower of oleander.

cup-shaped corona is seen in daffodil (*Narcissus*). The corona adds to the beauty of the flower and is thus an adaptation to attract insects for pollination.

Aestivation. The mode of arrangement of the sepals or of the petals, more particularly the latter, in a floral bud with respect to the members of the same whorl (calyx or corolla) is known as aestivation. Aestivation is an important character from the viewpoint of classification of plants, and may be of the following types:

(1) **Valvate** (FIG. 109A), when the members of a whorl are in contact with each other by their margins, or when they lie very close to each other without any overlapping, as in custard-apple, bullock's heart, madar, *Artabotrys*, etc.

(2) **Twisted or Contorted** (FIG. 109B), when one margin of the sepal or the petal overlaps that of the next one, and the other margin is overlapped by the third one, as in China rose, cotton, lady's finger, etc. Twisting of the petals may be clockwise or anticlockwise. In

China rose, however, both types (clockwise and anticlockwise) are commonly met with.

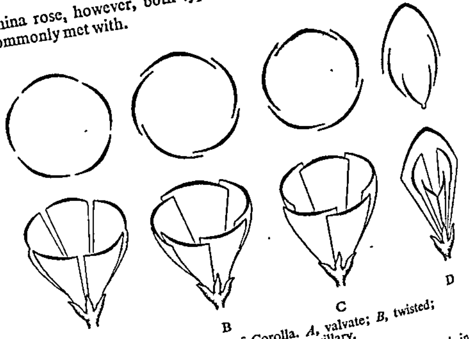


FIG. 109. Aestivation of Corolla. *A*, valvate; *B*, twisted; *C*, imbricate; *D*, vexillary.

(3) **Imbricate** (FIG. 109C), when one of the sepals or petals is internal being overlapped on both the margins, and one of them is external and each of the remaining ones is overlapped on one margin and it overlaps the next one on the other margin, e.g. *Cassia*, gold mohur, dwarf gold mohur, etc.

(4) **Vexillary** (FIG. 109D), when there are five petals, of which the posterior one is the largest and it almost covers the two lateral petals, and the latter in their turn nearly overlap the two anterior or smallest petals. Vexillary aestivation is universally found in all papilionaceous corollas (see also FIG. 105 as in pea family or *Papilionaceae*, e.g. pea, bean, butterfly pea, rattlewort, etc.

(3) Androecium

Androecium (*andros*, male) is composed of a number of stamens or microsporophylls. Each stamen consists of filament, anther and connective (FIG. 110). Each of the two anther-lobes has two chambers or loculi, called the pollen-sacs or *microsporangia*; thus there are altogether four loculi in each anther (FIG. 111). But in many cases there are only two, or even one. Each chamber of the anther is filled with pollen grains or *microspores*. The filament corresponds to the petiole of the leaf, the anther to the leaf-blade, and the connective to the mid-rib. A sterile stamen (without pollen grains) is known as a

staminode, as in pink, noon flower (*Pentapetes*), *Pterospermum* (see FIG. 92C), etc.

The Pollen. Pollen grains are very minute in size, varying from 10 to 200 microns, and are like particles of dust. Each pollen grain consists of a single microscopic cell, and possesses two coats: the exine and the intine. The exine is a tough, cutinized layer, which is often provided with spinous outgrowths or reticulations of different patterns, sometimes smooth. The intine, however, is a thin, delicate, cellulose layer lying internal to the exine. In pine the pollen grain is provided with two distinct wings. When the pollen grain has to germinate the intine grows out into a tube, called the pollen-tube (FIG. 113), through some definite thin and weak slits or pores, called germ pores, present in the exine (FIG. 112). Sometimes the pore is covered by a distinct lid which is pushed open by the growth of the intine. At first each pollen grain contains only one nucleus; this divides to

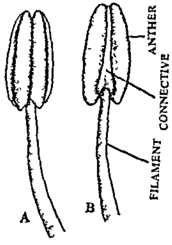


FIG. 110. Two stamens. *A*, face of the anther showing four pollen-sacs; *B*, back of the anther showing connective.

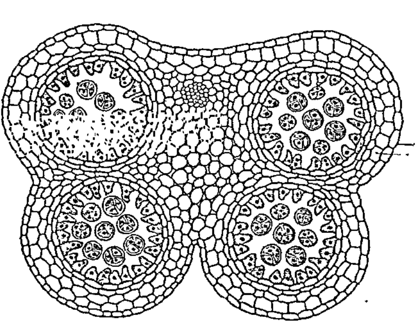


FIG. 111. An anther in transection showing four loculi and pollen grains in tetrads. Each tetrad separates into four pollen grains.

form two nuclei, of which the larger one is known as the vegetative nucleus or tube-nucleus and the smaller one the generative nucleus. As the pollen-tube grows it carries with it at its apex the tube-nucleus and the generative nucleus. The generative nucleus soon divides and two male reproductive units are formed, which are known as the

FIG. 112.
Pollen grains.
A, an entire grain;
B, a grain in section showing tube-nucleus (bigger one) and generative nucleus (smaller one).

FIG. 113.
Growth of the pollen-tube.

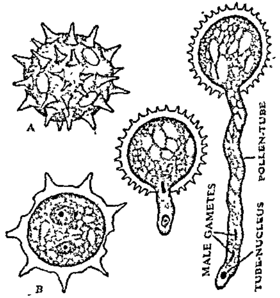


FIG. 112 FIG. 113

male gametes. The tube-nucleus then gets disorganized. (It may be noted that in angiosperms the pollen-tube with the tube-nucleus and the generative nucleus or the two male gametes represents an extremely reduced male gametophyte.)

and each pollen cell secretes a thick outer wall—the exine, and a thin inner wall—the intine (L). The four mature cells separate from one another and form four

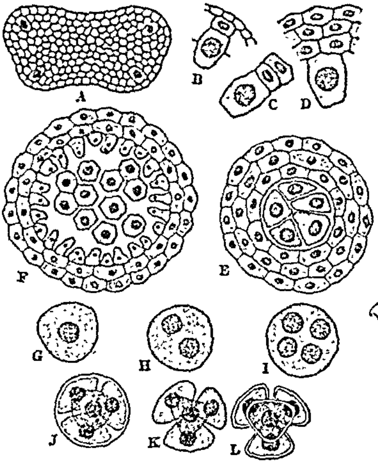


FIG. 114. *A-F*, development of anther; *G-L*, development of pollen grains. (Explanation in the text.)

pollen grains. In monocotyledons, however, the cleavage of the cytoplasm takes place by two planes at right angles to each other, *and not in a tetrahedral manner*, as in dicotyledons.

In bulrush (*Typha*; B. HOGLA; H. PATER), rush (*Juncus*), sundew (*Drosera*) and in *certain orchids, the four cells formed in a* group (tetrad) do not separate, but remain more or less coherent. In madar (*Calotropis*) and orchids the pollen cells of each pollen-sac instead of separating into loose pollen grains are united into a mass known as the *pollinium* (FIG. *115*). Pollen grains may also be in compound forms., i e. in small masses, as in *Acacia*, *Mimosa*, etc.

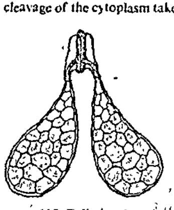


FIG. 115. Pollinia of madar (*Calotropis*).

Attachment of the Filament to the Anther (FIG. 116). There are four principal ways in which the filament is attached to the anther.

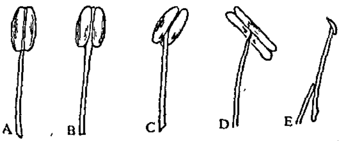


FIG. 116. *A*, basifixed or innate; *B*, adnate; *C*, dorsifixed; *D*, versatile, *E*, elongated connective of sage (*Salvia*) separating the two anther-lobes (upper one fertile and lower one sterile)

The anther is said to be (1) **basifixed or innate**, when the filament is attached to the base of the anther, as in mustard, radish, sedge, water lily, etc.; (2) **adnate**, when the filament runs up the whole length of the anther from the base to the apex, as in *Michelia*, *Magnolia*, etc.; (3) **dorsifixed**, when it is attached to the back of the anther, as in passion-flower; and (4) **versatile**, when it is attached to the back of the anther at one point only so that the latter can swing freely in the air, as in grasses, palms, spider lily (*Pancratium*), etc. In sage (*Salvia*; FIG. 116E) the filament is attached to the elongated connective separating the two anther-lobes, of which the upper one is fertile and the lower one sterile.

Cohesion of Stamens (FIG. 117). Stamens may either remain free or they may be united (coherent). There may be different degrees of

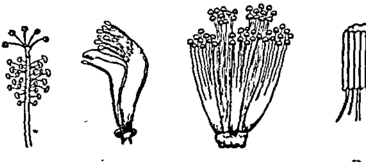


FIG. 117. Cohesion of Stamens. *A*, monadelphous; *B*, diadelphous; *C*, polyadelphous; *D*, syngenesious.

cohesion of stamens,
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anthers remaining fr
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free; or (c) the synandrous condition when the stamens are united by both the filaments and the anthers. Accordingly the following types are to be noted:

(1) **Monadelphous Stamens** (*monos*, single; *adelphos*, brother). When all the filaments are united together into a single bundle but the anthers are free, the stamens are said to be monadelphous (A), as in *Malvaceae*, e.g. China rose, lady's finger, cotton, etc. In them the filaments are united into a tubular structure, called staminal tube, ending in free anthers.

(2) **Diadelphous Stamens** (*di*, two). When the filaments are united into two bundles, the anthers remaining free, the stamens are said to be diadelphous (B), as in *Papilionaceae*, e.g. pea, bean, gram, butterfly pea, rattlewort, etc. In them there are altogether ten stamens of which nine are united into one bundle and the tenth one is free.

(3) **Polyadelphous Stamens** (*polys*, many). When the filaments are united into a number of bundles—more than two, but the anthers are free, the stamens are said to be polyadelphous (C), as in silk cotton tree, castor, lemon, etc.

(4) **Syngenesious Stamens** (*syn*, together or united; *gen*, producing). When the anthers are united together into a bundle or tube, but the filaments are free, the stamens are said to be syngenesious (D), as in *Compositae*, e.g. sunflower, marigold, etc.

(5) **Synandrous Stamens.** When the stamens are united throughout their whole length by both the filaments and the anthers, they are said to be synandrous (FIG. 118), as in *Cucurbitaceae*. Synandrous stamens are also found in *Araceae*, e.g. taro (*Colocasia*), etc.

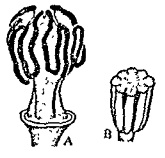


FIG. 118. Synandrous stamens. *A*, ash or wax gourd; *B*, taro.

Adhesion of Stamens. Stamens are said to be (1) **epipetalous**, when they are attached to the corolla wholly or partially by their filaments, as in *Datura*, *Ixora*, potato, sunflower, etc.; (2) **epiphyllous**, when attached to the perianth, as in *Liliaceae*; and (3) **gynandrous**, when united with the carpels, either wholly or by their anthers only, as in madar, orchids, etc.

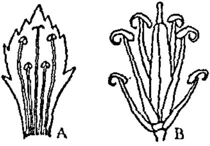


FIG. 119. Length of Stamens. *A*, didynamous; *B*, tetradynamous.

Length of Stamens (FIG. 119). In *Labiatae*, e.g. sacred basil (*Ocimum*), *Leonurus*, *Leucas*, etc., there are four stamens, of which two are long and two short; such stamens are said to

be (1) **didynamous** (*di*, two; *dynamis*, strength). In *Cruciferae*, e g mustard, radish, turnip, rape, etc., there are six stamens, of which four are long and two short; such stamens are said to be (2) **tetradynamous** (*tetra*, four). Sometimes different kinds of flowers, some with longer stamens and others with shorter stamens, are borne by the same plant (*dimorphic* stamens).

Dehiscence of the Anther. Dehiscence of the anther may be (1) **longitudinal**, as in China rose, cotton, *Datura*, etc.; (2) **transverse**, as in basil; (3) **porous** (by pores), as in potato, brinjal, etc.; and (4) **valvular** (by valves), as in cinnamon, camphor, bay leaf, etc.

(4) Gynoecium or Pistil

[illegible]

[illegible] The pistil may be simple [illegible] carpel) or **compound** (made of two or more carpels). In a compound pistil the carpels may be free, as in lotus, *Michelia*, rose, stonecrop [illegible]

[illegible]

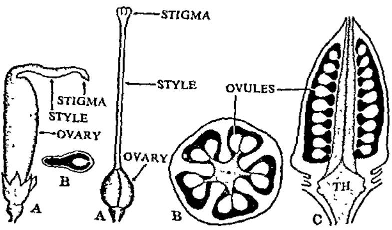


FIG. 120 FIG. 121

FIG. 120. Pistil. *A*, simple pistil of pea; *B*, one-chambered ovary of the the same. FIG. 121. *A*, syncarpous pistil; *B*, five-chambered ovary of the same (in transection); *C*, ovary of the same in longi-section. *TH*, thalamus.

monly found, when the pistil is said to be **syncarpous** (*syn*, together or united; FIG. 121A). Each pistil consists of three parts—stigma, style and ovary (FIG. 121A). The ovary contains one or more little, roundish or oval, egg-like bodies which are the rudiments of seeds and are known as the **ovules** (FIG. 121B-C). Each ovule encloses a

rge oval cell known as the embryo-sac (see FIG. 130). A sterile pistil s known as the pistillode. In position the style may be terminal,

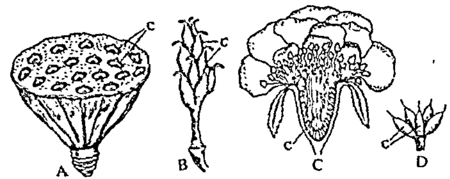


FIG. 122. Apocarpous Pistil. *A*, lotus; *B*, *Michelia*; *C*, rose; *D*, stonecrop (*Sedum*). *c*, carpels.

lateral or gynobasic. The gynobasic style (see FIG. 123) rises from the depressed centre of the four-lobed ovary, as if from its base or directly from the thalamus, as seen in *Labiatae* and also in heliotrope.

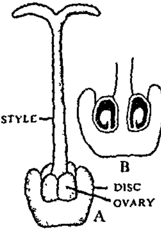


FIG. 123. Gynobasic style (*A*) of basil (*Ocimum*); *B*, the same in section.

The Ovary. The carpel is a metamorphosed leaf. The foliar nature of the carpel may be made out from the flowers of pea, bean, gram, etc., where a single carpel is present. In such cases the carpel or the pod may be compared to a leaf which has been folded along its midrib (FIG. 124). In a folded carpel when the two margins meet and fuse together a chamber is formed, the junction of the fused margins of the carpel being known as the *ventral suture*, and the midrib along which the carpel is folded being known as the *dorsal suture*. Along the ventral suture a ridge of tissue, called **placenta**, develops and bears the ovules. The closed chamber formed by the folding of the carpel, enclosing the ovules, is the **ovary**. In apocarpous pistil, as in buttercup (*Ranunculus*), the ovary is also formed in the above way (FIG. 125). In syncarpous pistil, however, the carpels may be united by their margins only, forming a one-chambered ovary, as in orchids (FIG. 126), or, the carpels may be folded inwards, their margins meeting in the centre, thus resulting in a many-chambered ovary with a central axis (FIG. 127), as in lily, China rose, etc. In gymnosperms, however, the carpels are not closed up to form the ovary and, therefore, there is no stigma, style or ovary. In them the

ovules are borne, freely exposed, along the margins of open carpe (see FIG. VI/3A-B).

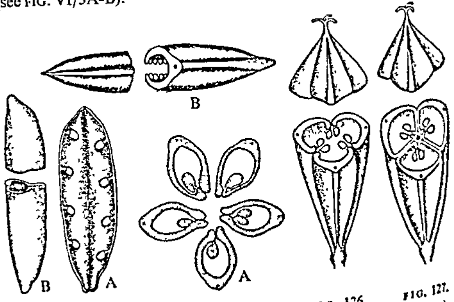
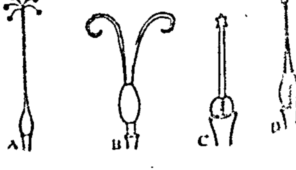


FIG. 124. FIG. 125. FIG. 126. FIG. 127.

Development of the Ovary. FIG. 124. *A*, a single carpel opened out with the ovules on the margins; *B*, one-chambered ovary formed by the folding of the carpel with ovules at the ventral suture. FIG. 125. *A*, one-chambered ovaries formed by five free carpels of an apocarpous pistil; *B*, one of the five ovaries (carpels). FIG. 126. One-chambered ovary formed by the union of margins of three carpels of a syncarpous pistil. FIG. 127. Three-chambered ovary formed by the infolding of three carpels and their margins meeting at the centre.

Cohesion of Carpels. The carpels may be united either throughout their whole length, as in most syncarpous pistils; or, they may be

FIG. 128.
Cohesion of carpels.
A, pistil with free stigmas in China rose;
B, the same with free styles in pink;
C, the same with free ovaries in oleander;
D, the same with free ovaries and styles in madar.



(*Vinca*), oleander (*Nerium*); or in the region of the stigma (and the style partly), as in madar (*Calotropis*).

Placentation

The placenta is a ridge of tissue—a parenchymatous outgrowth—in the inner wall of the ovary to which the ovule or ovules remain attached. The placentae most frequently develop on the margins of carpels, either along their whole line of union, called the **suture**, or at their base or apex. The manner in which the placentae are distributed in the cavity of the ovary is known as **placentation.** As a rule the origin of an ovule or a group of ovules determines the position of the placenta.

Types of Placentation (FIG. 129). In the simple ovary (of one carpel) there is one common type of placentation, known as **marginal,** and in the compound ovary (of two or more carpels united together)

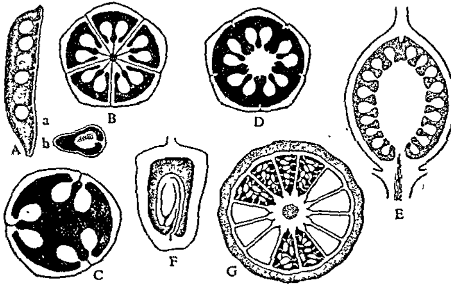


FIG. 129. Types of Placentation. *A*, marginal—*a*, in longi-section; *b*, in transection; *B*, axile; *C*, parietal; *D*, central; *E*, free-central; *F*, basal; and *G*, superficial.

placentation may be **axile, parietal, central, free-central, basal,** or **superficial.**

(1) **Marginal.** In marginal placentation (A) the ovary is one-chambered and the placenta develops along the junction of the two margins of the carpel, called the *ventral suture*, as in *Leguminosae* (e.g. pea, gram, gold mohur, *Cassia*, sensitive plant, etc.). The line, or suture, corresponding to the mid-rib of the carpel, is known as the *dorsal suture*. No placenta develops here.

nucellus, and it is surrounded by *two* coats, termed (6) the **integuments**. In gymnosperms, *Compositae* and a few other families with

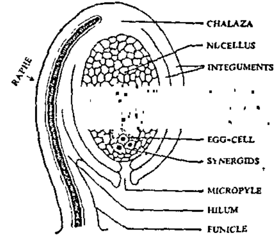


FIG. 130. An anatropous ovule in longitudinal section.

gamopetalous corolla there is only *one* integument. In parasites like sandalwood (*Santalum*) and *Loranthus* there is no integument. A small opening is left at the apex of the integuments; this is called (7) the **micropyle**. Lastly, there is a large, oval cell lying embedded in the nucellus towards the micropylar end; this is (8) the **embryo-sac**, that is, the sac that bears the embryo, and is the most important part of the ovule.

Development and Structure of the Embryo-sac. The *embryo-sac*, as shown in FIG. 130, develops in the following way (FIG. 131). The ovule

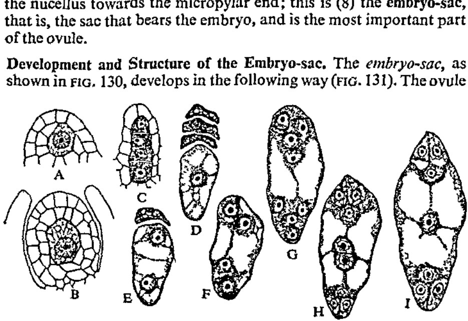


FIG. 131. Development of the embryo-sac. *A-H* are stages in its development; *I*, fully developed embryo-sac.

at first arises as a tiny protuberance from the placenta in the cavity of the ovary (A). In it even at a very early stage a cell, i.e. the mother

cell of the embryo-sac, becomes evident in the nucellus (B). This mother cell increases in size and *divides twice* to form a row of four megaspores, known as the linear tetrad (C). It is to be noted that of the two successive divisions of the mother cell the first one only is the reduction division (see FIG. II/21). Of the four cells, so formed, each with half (n) the usual number ($2n$) of chromosomes, the three upper ones degenerate and appear as dark caps, while *the lowest one* functions (D). The nucleus of this cell divides and the two daughter nuclei move to the two poles (E). [illegible] ber is increased to four (F). Each [illegible] altogether eight nuclei are formed in the embryo-sac, four at each end (G). The embryo-sac increases in size. Then *one* nucleus from each end or pole passes inwards, and the two polar nuclei *fuse together* somewhere in the middle, forming the definitive nucleus (H). The remaining three nuclei at the micropylar end, each surrounded [illegible]

Of the three cells constituting (1) the egg-apparatus, one is [illegible] female gamete known as (*a*) the egg-cell (or ovum or oosphere), and the other two are known as (*b*) the synergids (*synergein*, to co-operate) or co-operating cells. Synergids are more or less pear-shaped, and the egg-cell which is enlarged, lies below them. The egg-cell on fertilization gives rise to the embryo; while the synergids aid in the process of fertilization by guiding the pollen-tube and as soon as their function is over they become disorganized. The antipodal cells appear to have no definite function; so sooner or later they get disorganized. They may, however, be nutritive in function. They possibly represent vegetative cells of the extremely reduced female gametophyte. (In angiosperms the fully formed embryo-sac with the eight nuclei in it is regarded as the female gametophyte.) The definitive nucleus (FIG. 130) on fertilization (now called the **endosperm nucleus**) gives rise to the endosperm.

Forms of Ovules (FIG. 132). The ovule is said to be (1) **orthotropous** (*orthos*, straight; *tropos*, a turn) or **straight**, when the ovule is erect

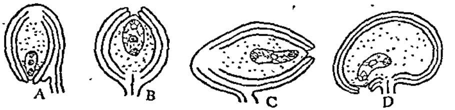


FIG. 132. Forms of Ovules. *A*, anatropous; *B*, orthotropous; *C*, amphitropous; *D*, campylotropous.

or straight so that the funicle, chalaza and micropyle lie in one and the same vertical line, as in *Polygonaceae*, e.g. *Polygonum*, sorrel (*Rumex*), etc., in *Piperaceae*, e.g. betel (*Piper betle*), long pepper (*Piper longum*), black pepper (*Piper nigrum*), and in *Casuarinaceae*, e.g. beef-wood tree (*Casuarina*); (2) **anatropous** (*ana*, backwards or up) or **inverted**, when the ovule bends along the funicle so that the micropyle lies close to the hilum; the micropyle and the chalaza, but not the funicle, lie in the same straight line; this is the commonest form of ovule; (3) **amphitropous** (*amphi*, on both sides) or **transverse**, when the ovule is placed transversely at a right angle to its stalk or funicle, as in duckweed (*Lemna*); and (4) **campylotropous** (*kampylos*, curved) or **curved**, when the transverse ovule is bent round like a horse-shoe so that the micropyle and the chalaza do not lie in the same straight line, as in several members of the following families—*Capparidaceae*, e.g. caper (*Capparis*), *Cruciferae*, e.g. mustard (*Brassica*), *Caryophyllaceae*, e.g. *Polycarpon*, *Chenopodiaceae*, e.g. *Beta*, *Chenopodium*, etc.

Position of the Ovule within the Ovary. An ovule may be (1) **ascending**, i.e. directed upwards, as in sunflower family or *Compositae* and basil family or *Labiatae*; (2) **pendulous**, i.e. turned downwards from the apex, as in *Euphorbia*, *Anemone*, coriander, anise, rose, etc.; (3) **suspended**, i.e. turned obliquely downwards from the side; and (4) **horizontal**, i.e. turned horizontally inwards from the side.

Chapter 7 POLLINATION

Towards the end of the 17th century Camerarius, as a result of his experimental work on mulberry, maize, castor, etc., carried out in Tubingen, established for the first time the fact that pollination is essential to the production of the seed. He distinguished the stamen with the pollen grains as the male organ and the pistil with the style and the ovary as the female organ. No further advance was made for several years. Koelreuter from 1764 to 1806 in Berlin, Leipzig and other places pollinated as many as 310 flowers. He realized the importance of insects and wind as pollinating agencies. He made also some plant hybrids. The actual process (fertilization) leading to seed-production, however, remained unravelled. But he made a very interesting observation. By microscopic examination of the pollen grains on the stigma he noticed that something—an oily substance—escaped from the grains and this, mixed with the oil secreted by the stigma, worked down into the style and entered into the ovary and there produced an embryo. Sprengel published in 1793 an account of his observations on many common wild flowers and made it clear for the first time that various adaptations of flowers are meant to achieve cross-pollination by means of insects. He further concluded from his observations on dichogamy and dicliny that nature does not intend that

flowers should be self-pollinated. Later a vast amount of work on pollination was carried out by Darwin, Müller, Knuth and Kerner.

Pollination is the transference of pollen grains from the anther of a flower to the stigma of the same flower or of another flower of the same or sometimes allied species, often through various agencies such [illegible] flower, evidently bisexual. Cross-pollination on the other hand is the transference of pollen grains from one flower to another flower. Cross-pollination may be of the following types: (*a*) xenogamy (*xenos*, stranger) when pollination takes place between flowers borne by two different plants of the same species; (*b*) geitonogamy (*geiton*, neighbour) when it takes place between two flowers borne by the same plant; and (*c*) **hybridism** when it takes place between two flowers borne by two different plants of allied species or even allied genera. In autogamy and geitonogamy only one parent plant is concerned in producing the offspring, while in xenogamy (cross-pollination in the strict sense) two parent plants are concerned and, therefore, a mingling of two sets of parental characters takes place resulting in healthier offspring. Both the methods are, however, widespread in nature.

A. SELF-POLLINATION OR AUTOGAMY

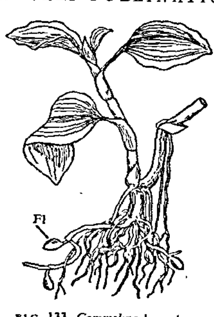


FIG. 133. *Commelina bengalensis*. *Fl*, underground flower.

The following adaptations are commonly met with in flowers to achieve self-pollination.

1. **Homogamy** (*homos*, the same). This is the condition in which the anthers and the stigmas of a *bisexual* flower mature at the same time. Under this condition some of the pollen grains may reach the stigma of the same flower through the agency of insects or wind or by the sudden bursting of the anther, thus effecting self-pollination.

2. **Cleistogamy** (*kleistos*, closed). There are some bisexual flowers which never open. They are called cleistogamous or closed flowers, and self-pollination is the rule in them. Cleistogamy is seen in the

underground flowers of *Commelina bengalensis* (FIG. 133), and also in some species of pansy (*Viola*), balsam (*Impatiens*), sundew (*Drosera*), wood-sorrel (*Oxalis*), etc.

B. CROSS-POLLINATION OR ALLOGAMY

Cross-pollination is brought about by external agents such as insects (bees, flies, moths, etc.), animals (birds, snails, etc.), wind and water. Cross-pollination is the rule in unisexual flowers, while in bisexual flowers it is of general occurrence. Nature favours cross-pollination and, therefore, adaptations in flowers to achieve it through external agents are many and varied.

1. **Entomophily** (*entomon*, an insect; *philein*, to love). Pollination by insects is of very general occurrence among plants. Entomophilous or insect-loving flowers have various adaptations by which they attract insects and use them as conveyors of pollen grains for the purpose of pollination. Principal adaptations are **colour, nectar** and **scent.**

Colour. One of the most important adaptations is the **colour** of the petals. In this respect the brighter the colour and the more irregular the shape of the flower the greater is the attraction. Sometimes, when the flowers themselves are not conspicuous, other parts may become coloured and showy to attract insects. Thus in *Mussaenda* (see FIG. 100) one of the sepals is modified into a large white or coloured leafy structure which serves as an 'advertisement' flag to attract insects. In some cases bracts become highly coloured and attractive, as in glory of the garden, poinsettia, etc. Spathes are often brightly coloured, as in bananas and aroids.

Nectar. Another important adaptation is the **nectar.** Nearly all flowers with gamopetalous corolla secrete nectar which is a positive attraction to the cleverer insects like bees. Nectar is contained in a special gland, called nectary, and sometimes in a special structure, called the spur (see p. 77). The nectary occurs at the base of one of the floral whorls, and as the bees which are very active pollinating agents collect the nectar from the nectary or the spur they incidentally bring about pollination.

Scent. The third adaptation is the **scent.** Most of the nocturnal flowers are insect-loving and they emit at night a sweet scent which attracts insects from a distance. At night, when the colour fails, the scent is particularly useful in directing the insects to the flowers. Thus nocturnal flowers are mostly sweet-smelling. Common examples are night jasmine (*Nyctanthes*), queen of the night (*Cestrum*), jasmines, Rangoon creeper (*Quisqualis*), etc. Sometimes the smell that is offensive and nauseating to human beings is immensely liked by certain small insects. Thus the appendix of the mature inflorescence of *Amorphophallus* (B. OL; H. KANDA—FIG. 134) emits a stinking smell, more

offensive than that of putrid meat; this always attracts a swarm of carrion-flies, and pollination is achieved through them.

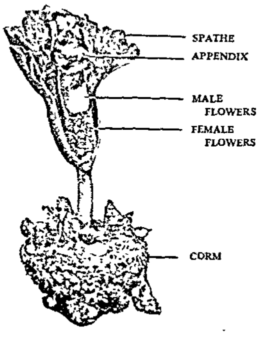


FIG. 134. Spadix of *Amorphophallus companulatus* (B. OL.; H. KANDA).

The pollen grains of entomophilous flowers are either sticky or provided with spinous outgrowths. The stigma is also sticky. Pollen grains and nectar sometimes afford excellent food for certain insects. Sometimes insects visit the flowers in search of shelter from sun and rain, and incidentally bring about pollination.

Special Adaptations. In sunflower, marigold, *Cosmos*, *Anthocephalus* (B. & H. KADAM), gum tree (*Acacia*), etc., where the individual flowers are small and inconspicuous, they are massed together into a dense inflorescence which evidently becomes much more showy and attractive. Dense inflorescence has another advantage; flowers being close together have every chance of being pollinated (see p. 62).

In *Ficus* (e.g. banyan, peepul, fig, etc.) the insects enter the hollowed out chamber of the fleshy receptacle through its narrow apical opening (see p. 65), and as they crawl over the unisexual flowers inside the chamber they bring about pollination (FIG. 135). Female flowers lie at the base of the cavity and open earlier, while male flowers lie near the apical opening and open later so that pollen grains have to be brought over from another inflorescence.

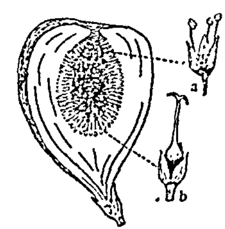


FIG. 135. Fig (*Ficus*) cut lengthwise. Note the apical pore guarded by scales. *a*, male flower; *b*, female flower.

In snapdragon (see FIG. 106B) and other flowers having personate corolla, only the insects of particular size and weight can open the mouth of the

corolla. Again long-tongued insects are only useful in the case of the flowers with long corolla-tube.

A very interesting case of cross-pollination by insects is seen in sage (*Salvia*; FIG. 136). There are two stamens in the flower, with the two anther lobes of each widely separated by the elongated curved connective which plays freely on the filament. The upper lobe is fertile and the lower one sterile. In the natural position the connective is upright. When the insect enters the tube of the corolla it pushes the lower sterile anther lobe of each stamen; the connective swings round with the result that the upper fertile lobe comes down and strikes the back of the insect and dusts it with pollen grains. The flower is protandrous, and later when the stigma matures it bends down and touches the back of another insect-visitor coming with pollen grains from another flower. Thus pollination is brought about. This is a special mechanism for cross-pollination.

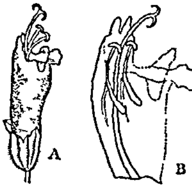


FIG. 136. Sage (*Salvia*). *A*, entire flower; *B*, showing elongated connective.

2. Anemophily (*anemos*, wind). In some cases pollination is brought about by wind. Anemophilous or wind-loving flowers are small and inconspicuous. They are never coloured or showy. They do not emit any smell nor do they secrete any nectar. The anthers produce an immense quantity of pollen grains, wastage during transit from one flower to another being considerable. They are also light and dry; sometimes, as in pine, they are provided with wings for facility of distribution by wind. Stigmas are comparatively large and protruding, sometimes branched and often feathery. Examples are afforded by grasses, bamboos, cereals, millets, sugarcanes, sedges, pines, and several palms. Anemophily is well illustrated by maize or Indian corn plant (FIG. 137). The plant bears a large number of male flowers (spikelets) in a terminal panicle, and lower down it bears 1 or 2 female spadices, with a tuft of fine, long and silky threads—the

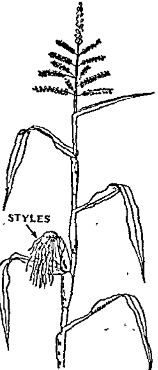


FIG. 137. Maize plant with male flowers in a panicle (on the top) and female flowers in a spadix (at the bottom). Note the styles dangling in the air.

styles—hanging from them. When the anthers burst a cloud of dust-like pollen grains is seen floating in the air close round the plant. Some of them are caught by the protruding stigmas, and thus pollination is effected. By far the greater majority of pollen grains are, however, blown away and wasted.

3. **Hydrophily** (*hydor*, water). Pollination may also be brought about in some aquatic plants, particularly the submerged ones, through the agency of water, e.g. *Naias*, *Vallisneria*, *Hydrilla*, *Ceratophyllum*, etc. Those aquatic plants that lift their flowers above the water normally achieve pollination through insects or wind. Hydrophily may be illustrated by *Vallisneria* (FIG. 138). The mode of pollination in it is

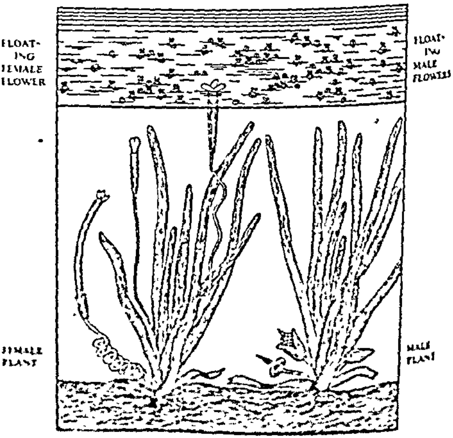


FIG. 138. *Vallisneria*. Female plant with a floating flower, a submerged flower (shut) and a fruit (6 inches long) maturing under water. Male plant with three spathes—young (covered by spathe), mature (with the spathe burst out) and old (after the escape of the male flowers). Male flowers are seen seen floating on water.

as follows. The plant is dioecious and submerged. The male plant bears a large number of very minute male flowers in a small spathe

surrounded by a spathe and borne on a short stalk, while the female plant bears solitary female flowers, each on a long slender stalk. The stalk quickly elongates and lifts the female flower to the surface of the water. The spathe bursts and the male flowers are released from the spadix, while still closed, and float on the surface of the water; the perianth expands giving buoyancy to them. Some of the floating male flowers come in contact with the female flowers. The anthers dehisce, and some of the sticky pollen grains adhere to the margins *and surfaces of the tri-fid stigmas which then close up. After pollina*tion the stalk of the female flower becomes spirally coiled and thus pulls the female flower down into the water. The fruit develops and matures under water a little above the bottom. Hydrophilous flowers are as a rule small and inconspicuous.

4. **Zoophily** (*zoon*, animal). Birds, squirrels, bats, snails, etc., also act as *useful agents of pollination; for example, birds and squirrels* bring about pollination in coral tree (*Erythrina*) and silk cotton tree (*Bombax*); bats in *Anthocephalus* (B. & H. KADAM); and snails in certain large varieties of aroids and in snake plant (*Arisaema*—see FIG. 80). (Insects are also instrumental in bringing about pollination in them.)

Advantages and Disadvantages of Self- and Cross-pollinations. Self-pollination has this advantage that it is almost certain in a bisexual flower provided that both *its stamens and carpels have matured at the same time.* Continued self-pollination generation after generation has, however, this disadvantage that it results in weaker progeny. *The advantages of cross-pollination are many,* as first shown by Darwin in 1876: (a) it always results in much healthier offspring which are better adapted to the struggle for existence; (b) more abundant and viable seeds are produced by this method; (c) new varieties may also be produced by the method of cross-pollination; and (d) the adaptability of the plants to their environment is better by this method. The disadvantages of cross-pollination are that the plants have to depend on external agencies for the purpose and, this being so, the process is more or less precarious and also less economical as various devices have to be adapted to attract pollinating agents, and that there is *always a considerable waste of material (pollen) when wind is the pollinating agent.*

Contrivances for Cross-pollination. The contrivances met with in flowers favouring cross-pollination, and wholly or *sometimes partially* preventing self-pollination, are many and varied. These are *as follows:*

(1) **Dicliny or Unisexuality.** Diclinous (*di*, two or asunder; *kline*, a bed) flowers are unisexual, i.e. stamens and carpels lie in separate flowers—male and female, either borne by the same *plant or by two* separate plants. It is thus evident that there are two cases of dicliny: (*a*) when the male and the female flowers are borne by one and the same plant, it (the plant) is said to be monoecious (*monos*, single; *oikos*, a house), e.g. gourd, cucumber, castor, maize, jack, etc.; and

palm, papaw, mulberry, etc. Cross-pollination

(2) Self-sterility. This is the condition in which the pollen of a flower has no fertilizing effect on the stigma of the same flower. As a matter of fact it is seen, as in some orchids, that the pollen has an injurious effect on the stigma of the same flower; the stigma, when the pollen is applied to it, dries up and falls off. Tea flowers, some species of passion-flower and Indian mallow (*Malva*) are also self-sterile. Pollen applied from another plant of the same or allied species is only effective in such cases. Cross-pollination is thus the only method in them for the setting of seeds.

(3) Dichogamy (*dicha*, in two). In many bisexual flowers the anther and the stigma often mature at different times. This condition is known as dichogamy. As the anther and the stigma come to maturity at different times, dichogamy often stands as a barrier to self-pollination. There are two conditions of dichogamy: (*a*) protogyny (*protos*, first; *gyne*, female) when the gynoecium matures earlier than the anthers of the same flower; here the stigma receives the pollen grains brought from another flower. Common examples are *Ficus* (fig, banyan, peepul, etc.), four o'clock plant, *Magnolia*, custard-apple, some palms, etc.; and (*b*) protandry (*protos*, first; *andros*, male) when the anthers mature (burst and discharge their pollen) earlier than the stigma of the same flower; here the pollen grains are carried over to the stigma of another flower. Common examples are *Clerodendron* (FIG. 139), China rose, cotton, lady's finger, sunflower, marigold, coriander, *Carum* (B. JOWAN; H. AJOWAN), wood-sorrel, rose, etc. Protandry is more commonly found than protogyny.

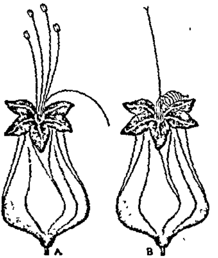


FIG. 139. Protandrous flowers of *Clerodendron*; *A*, stamens maturing first; *B*, stigma maturing later.

(4) Heterostyly (*heteros*, different). There are some plants which bear flowers of two different forms. One form bears long stamens and a short style, and the other form bears short stamens and a long style. This is known as *dimorphic* (*di*, two; *morphe*, form) heterostyly. Similarly there may be cases of *trimorphic* heterostyly, that is, stamens and styles of three different lengths borne by three different forms of flowers. In all such cases cross-pollination readily takes

place between stamens and styles of the same length borne by different flowers. Dimorphic heterostyly is seen in primrose, buckwheat, wood-sorrel (*Oxalis*), linseed (*Linum*) and *Woodfordia* (B. DHAIN-

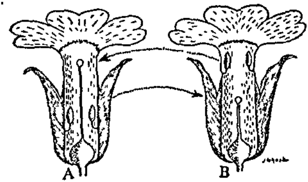


FIG. 140. Dimorphic flowers of primrose. *A*, a flower with long style; *B*, a flower with short style.

PHUL). Trimorphic heterostyly is found in some species of *Oxalis* and *Linum*.

(5) **Herkogamy** (*herkos*, a fence or barrier). In some homogamous flowers there are often certain adaptations of the floral parts which act as a fence or barrier to self-pollination and thus favour cross-pollination by insects. The two organs may lie at some distance from each other; the anthers may be inserted within the corolla tube and the style exserted, or the anthers exserted and the style inserted, or the anthers may be facing outwards, or they may be sheltered or hooded by the petals or by the petaloid style, as in *Iris*, or the relative position of anthers and stigmas may be such as to prevent self-pollination. Thus we find that the pollinia of orchids and madar (*Calotropis*) develop in a position whence they are not able to reach the stigmas by themselves. They also remain fixed in their position by adhesive discs, and can only be carried away by insects. The peculiar arrangement of stamens and pistil in sage (*Salvia*) to achieve cross-pollination has been already discussed (see p. 95). In pansy (*Viola tricolor*) the stigma is guarded by a flap or lid.

Chapter 8 FERTILIZATION

Fertilization is the fusion of two dissimilar sexual reproductive units, called *gametes*. In the 'flowering' plants the process of fertilization, first discovered by Strasburger in 1884, is as follows (FIG. 141). After pollination, that is, after the pollen grains reach the stigma, the intine of each grows out into a tube, called the pollen-tube (see FIG. 113),

through some thin or weak spots or *germ pores* in the exine (see FIG. 112). The growth of the pollen-tube is stimulated by sugary substances secreted by the [illegible]
pushes its way through [illegible]
side it, carrying with it the tube-nucleus and the generative nucleus. The generative nucleus divides forming two male gametes, while the tube-nucleus gets disorganized sooner or later. Sometimes, however, the generative nucleus divides before pollination. A mass of cytoplasm accumula[illegible]
embedded in it. [illegible]
finally it turns towards the micropyle of the ovule, whatever [illegible] position in the cavity of the ovary. The pollen-tube then passes through the micropyle and at length reaches the embryo-sac. This is

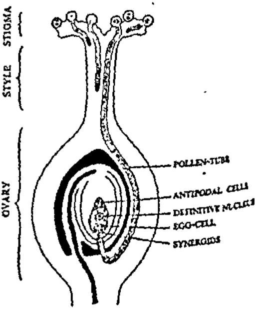


FIG. 141. Ovary in longitudinal section showing the process of fertilization. Note the two male gametes at the tip of the pollen-tube.

called porogamic fertilization and is the normal method. Sometimes, however, as in beef-wood tree (*Casuarina*; B. & H. JHAU), walnut (*Juglans regia*) and some species of *Betula*, the pollen-tube enters the embryo-sac through the base (chalaza) of the ovule, or even pierces the integuments. This is called chalazogamic fertilization, first discovered by Treub in 1891. After the pollen-tube enters the embryo-sac its tip dissolves and the male gametes are set free. Of the two gametes one fuses with the egg-cell (first observed by Strasburger in 1884); while the other pushes farther into the embryo-sac and fuses with the two polar nuclei or their fusion product, i.e. the definitive nucleus (first observed by Nawaschin in 1898). Thus fertilization (actually double fertilization which is the rule in angiosperms) is completed. The fusion of a male gamete with the two polar nuclei is [illegible]

termed *triple fusion*. In the process of fertilization synergids are supposed to direct the male gametes towards the egg-cell and the definitive nucleus, and as soon as fertilization is over they become disorganized. Antipodal cells have no positive function; so they disappear even before fertilization.[1] After fertilization the egg-cell clothes itself with a cell-wall and becomes known as the oospore. The oospore gives rise to the embryo, the ovule to the seed, and the ovary as a whole to the fruit, and the definitive nucleus, now called the endosperm nucleus, to the endosperm. If fertilization fails for some reason or other, the ovary simply withers and falls off. In certain cultivated varieties of banana, papaw, orange, grape, apple, pineapple, etc., the ovary may develop into the fruit without fertilization. The development of the fruit without fertilization is spoken of as parthenocarpy. Parthenocarpic fruits rarely contain seeds. The time involved between pollination and fertilization varies a good deal in different plants. Generally the time taken is from a few hours to a few days, but in some cases from a few to several months.

Double Fertilization. It must have been noted from the foregoing description that in angiosperms fertilization occurs twice: (*a*) one of the two male gametes of the pollen-tube fuses with the ovum of the embryo-sac, and (*b*) the other gamete fuses with the definitive nucleus which is the product of fusion of two polar nuclei during the development of the embryo-sac. This process is called double fertilization. It was first discovered by Nawaschin in 1898 in *Lilium* and *Fritillaria*. This amazing discovery attracted great attention and many investigators soon established the fact that this double fertilization is of universal occurrence among the angiosperms. The significance of double fertilization is not clearly understood. The fusion of one of the male gametes with the ovum results in the formation of the embryo; while the fusion of the other male gamete with the definitive nucleus results in the formation of the endosperm, and not in the formation of a sister embryo, as expected. It has been suggested that the presence of a second polar nucleus might be a disturbing element, and as such the definitive nucleus (endosperm nucleus) develops, as a result of *triple fusion*, into the endosperm instead of growing into an embryo.

Reduction Division. Pollen grains and embryo-sac are formed by the process of reduction division from their respective mother cells (see FIG. 114 and FIG. 131) and, therefore, the male gamete of the pollen-tube and the female gamete or egg-cell of the embryo-sac contain n chromosomes, i.e. half as many chromosomes as the mother cells. Then when these two gametes fuse together the number of chromosomes becomes doubled in the oospore ($n+n=2n$). This is how a constant number of chromosomes is maintained from generation to generation.

[1] Synergids and antipodal cells are generally regarded as vestigial structures, being remnants of the archegonium and the prothallus respectively.

Chapter 9 THE SEED

Development of the Seed. After fertilization a series of changes takes place in the ovule, and as a result the seed is formed. The fertilized egg-cell or ovum grows and gives rise to the embryo, and the definitive nucleus to the endosperm; other changes also take place in the ovule.

(1) **Development of the Embryo.** (*a*) *Dicotyledonous Embryo* (FIG. 142A). After fertilization the egg-cell or ovum secretes a cellulose wall

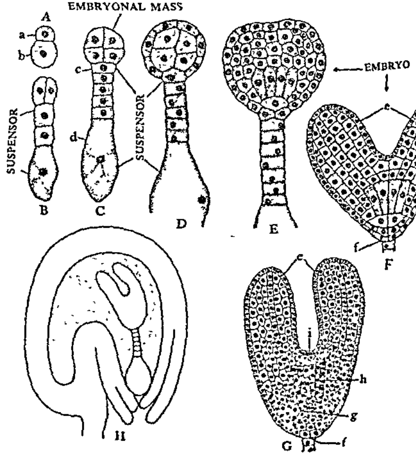


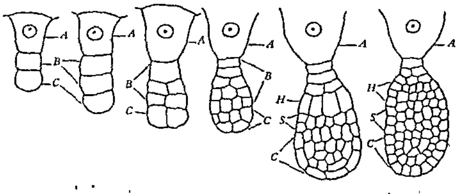
FIG. 142A. *A-H*, development of dicotyledonous embryo. *a*, embryonal cell; *b*, suspensor cell; *c*, hypophysis cell; *d*, basal cell of the suspensor; *e*, cotyledons; *f*, root-cap; *g*, root-tip; *h*, hypocotyl; and *i*, stem-apex. *H*, embryo within the seed.

round itself and becomes the oospore. The latter divides into two cells—an *upper* (away from the micropyle) and a *lower* (towards the

micropyle). The lower one lying towards the micropyle further divides in one direction into a row of cells, called the suspensor. The suspensor, as it elongates, pushes the developing embryo deep into the embryo-sac, and it also acts as a feeding organ to the embryo during the formation of the latter. For this purpose the basal cell of the suspensor often enlarges and acts as an absorbing organ. The suspensor, however, becomes disorganized as the radicle is formed. The terminal cell of the suspensor lying next to the embryonal mass is called the **hypophysis cell** (*hypo*, below; *physis*, growth). It divides and gives rise to the apex of the radicle. The upper cell lying away from the micropyle is called as the **embryonal cell.** It enlarges and divides by three walls at right angles into eight cells (octants or compartments), four cells lying towards the suspensor forming the posterior octants and the other four cells lying away forming the anterior octants. Each octant then divides by a wall parallel to its curved surface. Thus a surface (superficial) layer of cells and a central mass of cells, the latter being known as the **embryonal mass,** are formed. The surface layer divides in one direction by radial walls only and remains single-layered; finally it gives rise to the dermatogen, i.e. the outer layer of the stem-apex and the root-apex. The embryonal mass gives rise *to the whole of the embryo except the root-tip.* The cells of the embryonal mass divide repeatedly and the various parts of the embryo become differentiated. Thus it is seen that the **plumule** and the two **cotyledons** are derived from the anterior octants, and the main part of the **radicle** and the **hypocotyl** from the posterior octants. The apex of the radicle, as already stated above, is derived from the hypophysis cell.

(*b*) *Monocotyledonous Embryo* (FIG. 142B). Although the mono-

A B C D E F



cotyledonous embryo follows the same general trend of development as the dicotyledonous one the former has only *one* cotyledon against

the latter's *two*. Besides, in some monocotyledons the cotyledon is terminal and the stem-apex is lateral, although in others the reverse is the case as in dicotyledons. There is also a considerable variation in the details of development of monocotyledonous embryos. A typical case may be as follo[illegible]
one (lying towards [illegible]
a massive suspensor. The lower cell is the embryonal cell. It soon divides into two. The terminal cell of these two by repeated divisions in different planes gives rise to the single cotyledon. The other cell also divides in the same way and gives rise to the stem-apex, the hypocotyl and the root-tip.

(2) **Development of the Endosperm.** After the fusion of one of the male gametes with the definitive nucleus (i.e. as a result of *triple fusion*) the latter, now called the endosperm nucleus, begins to grow. It divides and gives rise to a large number of small nuclei (see FIG. II/23). Protoplasm collects round each of the nuclei, and finally cell-walls are formed between them. A tissue—food storage tissue—is thus formed by a process of free cell formation, which is known as the **endosperm**. As it grows it fills up the nucellus. In many seeds no endosperm is seen at maturity although it is always formed at the initial stage of embryo development. This is explained by the fact that the embryo, in the process of development, continually draws on the food stored up in the endosperm, and completely exhausts it. In some cases, as in water lily, ginger family, four o'clock plant and glory of the garden the nucellus persists and grows into a nutritive tissue like the endosperm, called the **perisperm**. The perisperm surrounds the endosperm.

(3) **Other Changes in the Ovule.** The two integuments develop into two seed-coats, of which the outer one is called the *testa* and the inner one the *tegmen*. In some seeds, as in water lily, nutmeg, wild mangosteen (B. GAB; H. KENDU), etc., there is usually found an outgrowth of the funicle, which grows up around the ovule and more or less completely envelops the seed; an outgrowth of this nature is called an aril; the mace (B. JAITRI) of nutmeg is the aril, and so also is the flesh of litchi and *Baccaurea* (B. LATKAN; H. LUTKO). In *Pithecolobium* (B. & H. DEKANI-BABUL) also the aril is fleshy and edible. A small outgrowth formed at the micropyle may also be seen in some seeds, as in castor, balloon vine etc.; this is known as the caruncle (see FIG. 146).

A. DICOTYLEDONOUS SEEDS

Parts of Exalbuminous Seeds (gram, pea, country bean, gourd, tamarind, mango, sunflower, etc.). Seed-coats consist of two layers or integuments, united or free, the outer being called testa and the inner tegmen, and are provided with hilum (representing the point of attach-

ment with the stalk), **micropyle** (a minute opening above the hilum) and **raphe** (*a ridge formed by the funicle or stalk in many seeds*). **Embryo** lying within consists of an **axis** and two fleshy **cotyledons** laden with food material. The pointed end of the axis is the **radicle** and the feathery or leafy end the **plumule**. As the seed germinates the radicle gives rise to the root and the plumule to the shoot.

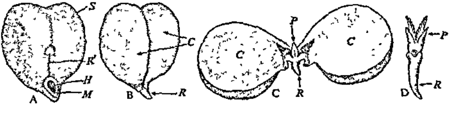


FIG. 143. Gram seed. *A*, entire seed; *B*, embryo (after removal of the seed-coat); *C*, embryo with the cotyledons unfolded; and *D*, axis of embryo. *S*, seed-coat; *R'*, raphe; *H*, hilum; *M*, micropyle; *C*, cotyledons; *R*, radicle; and *P*, plumule.

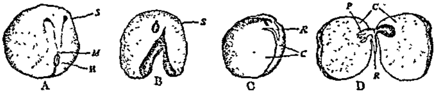


FIG. 144. Pea seed. *A*, entire seed; *B*, seed-coat with hilum and micropyle; *C*, embryo (after removal of the seed-coat); and *D*, embryo with the cotyledons unfolded. *S*, seed-coat—testa (it encloses a thin membranous tegmen); *M*, micropyle; *H*, hilum; *R*, radicle; *C*, cotyledons; *P*, plumule.

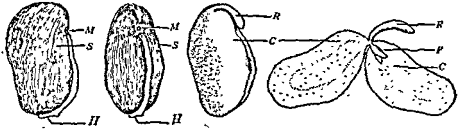


FIG. 145. Country bean seed. *M*, micropyle; *S*, seed-coat; *H*, hilum; *R*, radicle; *C*, cotyledons; *P*, plumule.

Parts of Albuminous Seeds (castor, papaw, custard-apple, four o'clock plant, etc.). **Castor Seed.** Seed-coats consist of an outer hard and blackish integument—the **testa** and an inner thin and whitish integument—the *tegmen*. *The outgrowth formed at the micropyle is* the **caruncle**; it absorbs moisture and helps germination. **Hilum** is almost hidden by the caruncle. The **raphe** is prominent. **Endosperm**

is the fleshy food storage tissue, rich in oil, lying immediately within the tegmen. Embryo lies embedded in the endosperm and consists of an axis with a distinct radicle pointing outwards and an undifferentiated plumule, and two thin, flat cotyledons with distinct veins.

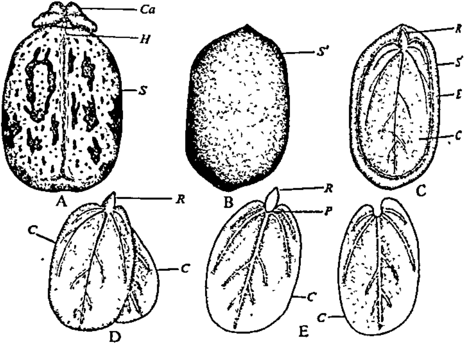


FIG. 146. Castor seed. *A*, an entire seed; *B*, the seed enclosed by the tegmen; *C*, the same split edgewise showing the embryo lying embedded in the endosperm; *D*, the embryo; and *E*, the same with the two cotyledons separated *Ca*, caruncle; *H*, hilum; *S*, testa; *S'*, tegmen; *R*, radicle, *E*, endosperm; C, cotyledon; and *P*, plumule.

B. MONOCOTYLEDONOUS SEEDS

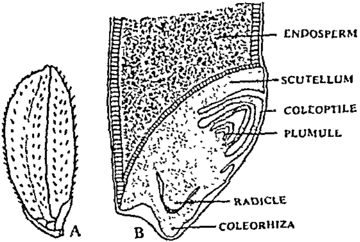
Parts of Albuminous seeds (rice, maize, wheat, onion, palms, etc.). **Rice Grain and Maize Grain.** The grain in each case is a small one-seeded fruit called caryopsis. Each grain remains enclosed by a brownish husk which consists of four parts, called *glumes*, arranged in two rows; the two minute ones at the base are *empty glumes*, while the two bigger ones enclose a flower; of these two the outer and slightly bigger one is called the *flowering glume*, while the inner and slightly smaller one, partially enveloped by the former, is called the *palea*. Each grain consists of the following parts.

(1) **Seed-coat** is the brownish membranous layer adherent to the grain. This layer is made up of the seed-coat and the wall of the fruit fused together.

(2) **Endosperm** forms the main bulk of the grain and is the food storage tissue of it, being laden with reserve food material, partic

larly starch. In a longitudinal section of the grain it is seen to be distinctly separated from the embryo by a definite layer known as the *epithelium*.

FIG. 147.
Rice grain.
A, the grain enclosed in husk (consisting of glumes);
B, the grain in longitudinal section (a portion).



(3) **Embryo** is very small and lies in a groove at one end of the endosperm. It consists of only (*a*) *one* shield-shaped cotyledon known as the **scutellum**, and (*b*) a short axis with (i) the **plumule**, and (ii) the **radicle** protected by the **root-cap**. The plumule as a whole (growing

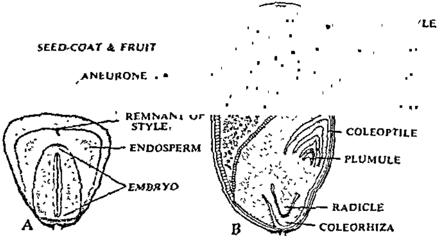


FIG. 148. Maize grain. *A*, the entire grain; *B*, the grain in longitudinal section.

point and foliage leaves) is surrounded by a protective sheath called the plumule-sheath or **coleoptile**; similarly the radicle (including the root-cap) is surrounded and protected by a root-sheath called the **coleorhiza**. The surface layer of the scutellum lying in contact with the endosperm is the **epithelium**; its function is to digest and absorb food material stored in the endosperm.

In cereals (e.g. rice, wheat, maize, barley and oat), millets and other plants of the grass family the cotyledon is known as the **scutellum**. It supplies the growing embryo with food material absorbed from the endosperm with the help of the **epithelium**.

Monocotyledonous seeds are mostly albuminous; a few exalbuminous ones are orchids, water plantain (*Alisma*), arrowhead (*Sagittaria*), *Naias*, etc.

Germination

The embryo lies dormant in the seed, but when the latter is supplied with moisture the embryo becomes active and tends to grow and develop into a small seedling. *The process by which the dormant embryo wakes up, grows out of the seed-coat and establishes itself as a seedling is called* **germination**. The embryo grows by absorbing the food material stored up in the cotyledons, or in the endosperm when it is present. Two kinds of germination will be noticed: epigeal and hypogeal.

1. Epigeal Germination (FIGS. 149-51). In some seeds such as tamarind, cucumber, cotton, gourd, castor, papaw, etc., the cotyledons

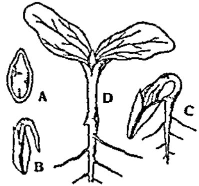


FIG. 149.

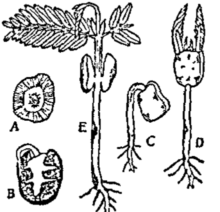
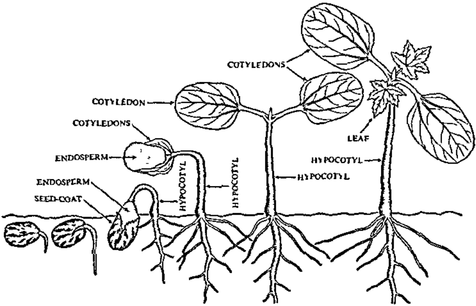


FIG. 150.

Epigeal Germination. FIG. 149. Gourd seed. FIG. 150. Tamarind seed.

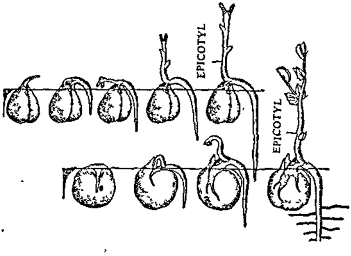
while in other such cases, particularly when the cotyledons are very thick, as in tamarind, sword bean, etc., they do not turn leafy, but gradually shrivel up and fall off.

2. **Hypogeal Germination** (FIGS. 152-3). In other seeds such as gram, pea, mango, litchi, jack, broad bean, groundnut, etc., the cotyledons



Epigeal Germination. FIG. 151. Castor seed.

are seen to remain in the soil or just on its surface. In such cases the **epicotyl**, i.e. the portion of the axis lying immediately above the cotyledons, elongates and pushes the plumule upwards. The coty-



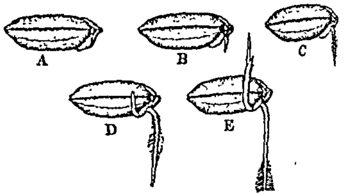
Hypogeal Germination.

FIG. 152. Gram seed.

FIG. 153. Pea seed.

ledons do not turn green, but gradually dry up and fall off. Germination of this kind is called hypogeal or hypogeous (*hypo*, below; *ge*, earth).

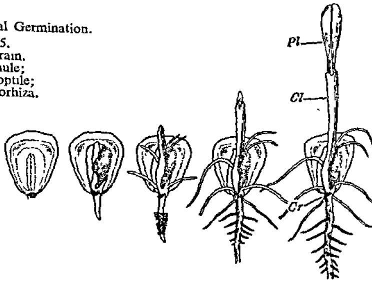
Hypogeal Germination of Monocotyledonous Seeds (FIGS. 154-5). Monocotyledonous seeds are mostly albuminous and in their germi-



Hypogeal Germination.
FIG. 154.
Paddy.
A-E, stages in germination.

nation the cotyledon and endosperm remain buried in the soil; germination is, therefore, hypogeal (except in the case of onion; see FIG. 158). In the germination of monocotyledonous seeds like paddy and maize, the cotyledon (or scutellum) absorbs the food material stored up in the endosperm. On germination the radicle makes its way through the lower short, collar-like end of the sheath called the root-sheath or **coleorhiza**; while the plumule breaks through the upper distinct cylindrical portion of the sheath, called the plumule-sheath or **coleoptile** (FIGS. 154-5 & 159-60). The radicle grows down-

Hypogeal Germination.
FIG. 155.
Maize grain.
Pl, plumule;
Cl, coleoptile;
Cr, coleorhiza.



wards and at first it develops into the primary root. In most cases the primary root soon perishes and a cluster of fibrous roots appears from the base. The plumule grows upwards. The first leaf soon emerges out of the plumule-sheath and others follow in succession.

In the germination of many palms, e.g. date-palm and palmyra-palm (but not coconut-palm) a part of the cotyledon extends into a sheath, long or short, which encloses the axis of embryo a little behind the tip and carries it down to some depth in the soil (see FIGS. 159-60).

Special Type of Germination. Many plants growing in salt-lakes and sea-coasts show a special type of germination of their seeds, known as **vivipary** (FIG. 156). The seed germinates inside the fruit while still attached to the parent tree and nourished by it. The radicle elongates, swells in the lower part and gets stouter. Ultimately the seedling separates from the parent plant due to increasing weight, and falling vertically becomes embedded in the soft mud below. The radicle presses into the soil, and quickly lateral roots are formed for proper anchorage. Examples are seen in *Rhizophora*, *Sonneratia* (B. KEORA), *Heritiera* (B. SUNDRI), etc.

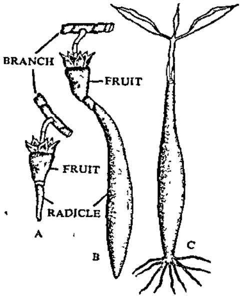


FIG. 156. Viviparous germination. *A-B*, stages in germination; *C*, seedling.

Conditions Necessary for Germination. Dry seeds retain their viability for many months and even years depending on their nature, provided, of course, that the embryo is not damaged by insects or fungi. Then the following external conditions are necessary for their germination: (1) water or moisture, (2) moderate temperature, and (3) air or oxygen.

(1) **Moisture.** For germination of a seed protoplasm must be saturated with water. In air-dried seeds the water content is usually 10-15 per cent. No vital activity is possible at this low water content. Water is thus necessary to bring about the vital activity of the dormant embryo; to dissolve various salts and to hydrolyse many organic substances stored in the cotyledons or in the endosperm; to facilitate necessary chemical changes; and to help the embryo to come out easily by softening the seed-coat.

(2) T[illegible] minati[illegible] range of temperature. Within limits which vary according to the nature of the seed, the higher the temperature the more rapid is the germination.

(3) **Air.** Oxygen is necessary for respiration of a germinating seed. By this process a considerable amount of energy stored in the food material is liberated and made use of by the protoplasm. Respiration in the germinating seed is very vigorous as the active protoplasm requires a constant supply of oxygen, and hence the seed sown deeply in the soil shows very little or no sign of germination.

It may be noted in this connexion that **light** is not an essential condition of germination. In fact seeds germinate *more* quickly in the dark. Some seeds—tomato, for example—will not germinate unless they are kept in the dark. Fo [illegible] indispensable. Seedlings that [illegible] gate rapidly but become frail, develop no chlorophyll and bear only pale, undeveloped leaves. Such seedlings are said to be *etiolated.*

Three Bean Experiment (FIG. 157). That all the conditions mentioned above are essential for germination can be shown by a simple experiment, known as the three bean experiment. Three air-dry seeds are attached to a piece of wood, one at each end and one in the middle. This is then placed in a beaker, and water is poured into it until the middle seed is half immersed in it. The beaker is then left in a warm place for a few days. From time to time water is added to maintain the original level. It is seen that the middle bean germinates normally because it has sufficient moisture, oxygen and heat. The bottom bean has sufficient moisture and heat, but not oxygen. It may be seen to put out only the radicle, but further development is checked for want of oxygen. The *top* bean having sufficient oxygen and heat only but not moisture, does not show any sign of germination.

FIG. 157. Three bean experiment.

This experiment evidently shows that moisture and oxygen are indispensable for germination; the effect of temperature is only indirectly proved. It can, however, be directly proved in the following way. Other conditions remaining the same, if the temperature be considerably lowered or increased by placing the beaker with seeds in a freezing mixture or in a bath with high constant temperature it will be seen that none of the beans will germinate. Thus suitable temperature is also an essential condition for germination.

ADDITIONAL MONOCOTYLEDONOUS SEEDS

1. **Onion Seed** (FIG. 158) **Structure.** The seed is small, black, roughly semicircular in shape, flattened on one side and grooved at the narrow end. Its outer black covering is (a) the seed-coat or testa. Cut the seed lengthwise and observe (b) the endosperm which is the thin whitish mass within the seed-coat, and (c) the embryo which is the slender, elongated, colourless, curved body lying embedded in the endosperm. The embryo consists of (i) a single cotyledon and (ii) a radicle. The bigger portion of the curved body looped at the end is the cotyledon, and the narrow end of it directed towards the pointed end of the seed is the radicle. The plumule which is very minute and undifferentiated lies hidden laterally in

the region of the very short hypocotyl, and is distinguishable clearly only on the germination of the seed.

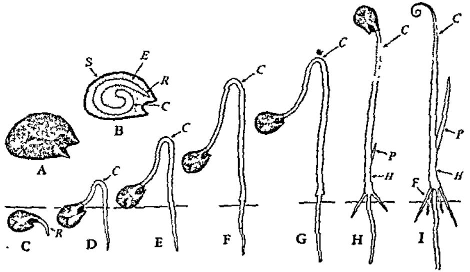


FIG. 158. Onion seed. *A*, an entire seed; *B*, the seed in longitudinal section; *C–I*, stages in germination; *S*, seed-coat; *E*, endosperm; *R*, radicle; *C*, cotyledon; *P*, plumule; *H*, hypocotyl; and *F*, fibrous roots.

Germination. As germination takes place the radicle comes out through the pointed end of the seed and grows downward (C). The cotyledon elongates, emerges out of the seed except for its looped end and forms a distinct arch or loop (D). It turns green in colour and further elongates as a leaf-sheath lifting the seed from the soil (E). The germination is epigeal. The end of the cotyledon still coils within the seed and functions as an absorbing organ drawing food from the endosperm and supplying the same to the growing parts. The root elongates further and the cotyledon turns deep green in colour functioning as the first leaf (F-G). The cotyledon grows further and almost straightens out bearing the seed on the top (H). A slight swelling appears at the base of the hypocotyl and a few fibrous roots push out from this region. A little higher up the plumule soon pierces the leaf-sheath and grows upward as a slender body. It turns green and forms the second leaf of the seedling. The coiled end of the cotyledon withers and the seed-coat drops now or a little later (I) By this time the endosperm has already become exhausted.

2-3. Date-palm Seed and Palmyra-palm Seed (FIGS. 159-60). The stony covering of the date-palm seed represents the seed-coat and the endocarp of the fruit; in the palmyra-palm seed the shell is the endocarp, while the inner brownish layer is the seed-coat. In both the seed-coat is adherent to the endosperm. Other parts in both are: a large endosperm filling up the cavity of the seed, and a small undifferentiated embryo lying embedded in the endosperm on one side.

When germination begins the single cotyledon enlarges, and a portion of it breaks through the seed-coat in the form of a sheath enclosing the axis of the embryo inside it. This sheath of the cotyledon elongates and carries down with it the axis of the embryo. After it has gone into the soil the radicle of the axis comes out piercing the root-sheath or coleorhiza, grows downwards and produces the

root. Eventually the plumule bursts the plumule-sheath or coleoptile and grows upwards into the air, forming the shoot.

FIG. 159.
Date-palm seed.
A, seed in section;
B, germinating seed in section;
C, seedling.
S, seed-coat and inner wall of the fruit;
E, endosperm;
Em, embryo (undifferentiated);
C, cotyledon;
Sh, sheath of cotyledon;
Cl, coleoptile;
Cr, coleorhiza.

FIG. 160.
Palmyra-palm seedling.
M, mesocarp (fibrous);
E, endocarp (stony);
S, endosperm with seed-coat;
C, cotyledon (spongy);
Sh, sheath;
Cl, coleoptile;
Cr, coleorhiza.

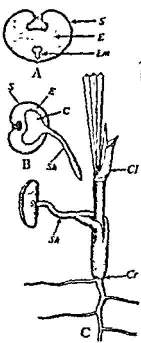


FIG. 159

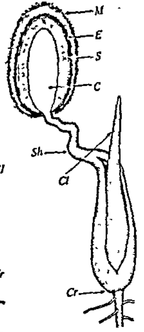


FIG. 160

4. Coconut-palm Seed (FIG 161). On removing the fibrous coat and breaking open the shell a black covering—a thin layer—adherent to the endosperm is

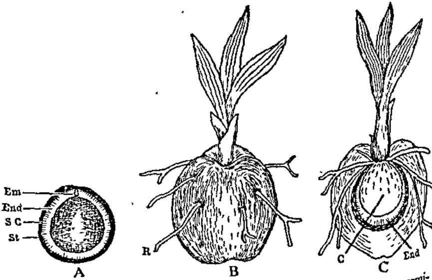


FIG. 161. Coconut-palm seed *A*, the seed cut lengthwise; *B*, germinating fruit, *C*, the same cut lengthwise; *Em*, embryo; *End*, endosperm; *S.C*, seed-coat; *St*, stone; *R*, root; *C*, cotyledon.

seen; this is the seed-coat. The white, thick mass is the endosperm. The embryo lies as a small, undifferentiated body at one of the three 'eyes'. In the germination of the coconut-palm seed a regular sheath is not formed, as in other palms, and the undifferentiated embryo germinates *in situ*. Its lower end extends and forms a single cotyledon which gradually enlarges and swells into a spherical, white, spongy body and fills the whole cavity of the seed. With the growth of the cotyledon the endosperm is seen to thin out. The upper end of the embryo develops into a small shoot with a number of fibrous roots produced at its base. These roots pierce the thick fibrous coat of the fruit, and come out in different directions.

SEEDS

Dicotyledonous	exalbuminous	epigeal, e.g. bean, gourd, tamarind, cotton, sunflower, etc.
		hypogeal, e.g. gram, pea, mango, etc.
	albuminous	epigeal, e.g. castor, papaw, poppy, four o'clock plant, etc.
		hypogeal, e.g. *Annonaceae*.
Monocotyledonous	exalbuminous	epigeal, e.g. water plantain (*Alisma*).
		hypogeal, e.g. *Aponogeton*.
	albuminous	epigeal, e.g. onion and other *Liliaceae*.
		hypogeal, e.g. rice, maize, palms, etc.

Chapter 10 THE FRUIT

Development of the Fruit. Apart from the development of the seed fertilization stimulates the growth of the ovary also. As it grows and matures it becomes converted into the fruit. The fruit may, therefore, be regarded as a mature or ripened ovary. A fruit consists of two portions, viz. the pericarp (*peri*, around; *karpos*, fruit) developed from the wall of the ovary, and the seeds developed from ovules. The [illegible] hick, it may consist of two or [illegible] orms the skin of the fruit; the [illegible] uits like mango, peach, *palms*, etc., and the inner, called *endocarp*, is often very thin and membranous, as in orange, or it may be hard and stony, as in many palms, mango, etc. In many cases, however, the pericarp is not diff[illegible] into these three regions.

When only the ovary of the flower grows into the fruit, it is commonly known as the true fruit, but often it is found that other floral parts such as the thalamus, receptacle, or calyx may also grow and form a part of the fruit; such a fruit is known as the false or spurious **fruit** or pseudocarp. Thus in *Dillenia* (B. & H. CHALTA) the calyx is persistent and fleshy forming the prominent part of the fruit. In apple (FIG. 162A) and pear the thalamus grows round the inferior ovary

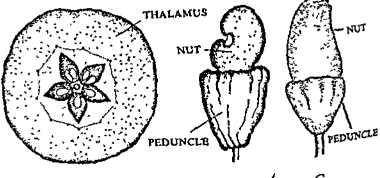


FIG. 162. *A*, apple cut transversely; *B*, cashew-nut (*Anacardium*); *C*, marking-nut (*Semecarpus*).

and becomes fleshy in the fruit. In cashew-nut (*Anacardium*; FIG. 162B) the peduncle and the thalamus grow and become swollen and fleshy forming an edible fruit-like body which is a false fruit or pseudocarp, while the actual fruit which is an edible reniform nut, developing from the ovary, is seated on the swollen peduncle. Simi-
[illegible] 162C) [illegible]

Dehiscence of Fruits (FIG. 163). There are many ways of dehiscence of fruits to liberate their seeds. It may be of the following types.

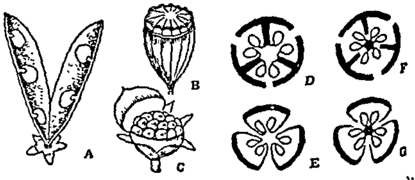


FIG. 163. Dehiscence of fruits. *A*, sutural (pea); *B*, porous (poppy); *C*, transverse (cock's comb); *D*, loculicidal; *E*, septicidal; *F-G*, septifragal.

(1) Transverse (C), as in cock's comb (*Celosia*), purslane (*Portulaca*), etc. (2) Porous (B), i.e. by pores, as in poppy, bath sponge, etc. (3) Valvular, i.e. bursting partially or completely into pieces called valves. It may be of the following kinds: (*a*) sutural (A), i.e. opening by one or both the sutures, as in periwinkle, pea, bean, etc.; (*b*) loculicidal (D), i.e. splitting through the back of the loculus (chamber), as in cotton, lady's finger, *Ruellia*, *Andrographis*, etc.; (*c*) septicidal (E), i.e. dehiscing through the septa (partition walls), as in linseed, devil's cotton (*Abroma*), mustard, etc.; and (*d*) septifragral (F-G), i.e. dehiscing loculicidally or septicidally, with the valves falling away leaving the seeds attached to the central axis, as in thorn-apple (*Datura*), toon (*Cedrela*), *Pterospermum*, etc.

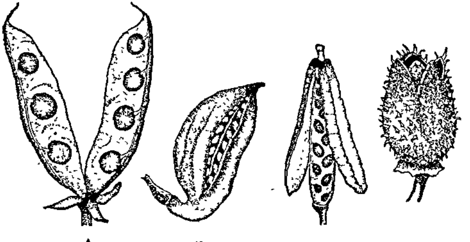
Classification of Fruits

Fruits, whether true or spurious, may be broadly classified into three groups, viz. simple, aggregate and multiple or composite.

A. Simple Fruits. When only one fruit develops from the single ovary (either of simple pistil or of syncarpous pistil) of a flower with or without accessory parts (true or spurious fruits as explained above), [illegible] be dry or fleshy. Dry [illegible] hizocarpic (in which [illegible] 1-seeded parts).

I. DEHISCENT OR CAPSULAR FRUITS

(1) **Legume** or **Pod** (FIG. 164A). This is a dry *monocarpellary* fruit developing from a superior, one-chambered ovary and dehiscing by



A B C D

FIG. 164. Fruits. *A*, legume or pod of pea; *B*, follicle of madar (*Calotropis*); *C*, siliqua of mustard; *D*, capsule of thorn-apple (*Datura*).

both the sutures, as in *Papilionaceae*, e.g. pea, bean, groundnut, pulses, rattlewort (B. ATASHI; H. JHUNJHUNIA), etc.

(2) **Follicle** (FIG. 164B). This also is a dry, *monocarpellary*, superior, one-chambered fruit like the previous one, but it dehisces by one suture only, as in madar (*Calotropis*), blood flower (*Asclepias*), periwinkle (*Vinca*), *Michelia*, etc. Follicles commonly occur in a pair or in a cluster.

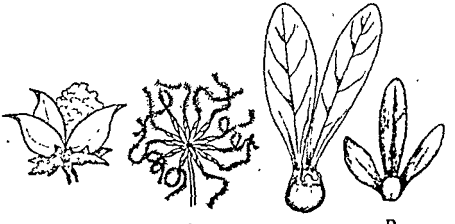
(3) **Siliqua** (FIG. 164C). This is a long, narrow, many-seeded fruit developing from a superior, *bicarpellary* ovary with two parietal placentae. It dehisces from below upwards by both the sutures. The ovary is one-chambered at first, but as it grows into the fruit it becomes two-chambered, owing to the development of a false partition wall, called *replum*, which extends from one placenta to the other. Siliqua is found in *Cruciferae*. A short, broad and flat siliqua, as that of shepherd's purse (*Capsella*), is called a silicula.

(4) **Capsule** (FIGS. 164D & 165A). This is a many-seeded, uni- or multilocular fruit developing from a superior (or sometimes inferior), [illegible]

as capsules, e.g. poppy, cotton, lady's finger, *Datura*, etc.

II. INDEHISCENT OR ACHENIAL FRUITS

(1) **Caryopsis** (see FIGS. 147 & 148). This is a very small, dry, one-seeded fruit developing from a superior, *monocarpellary* ovary, with the pericarp fused with the seed-coat. Examples are found in *Gramineae*, e.g. rice, wheat, maize, etc.



A B C D

FIG. 165. Fruits (*contd.*). *A*, capsule of cotton; *B*, achenes of *Naravelia*; *C*, samara of *Dipterocarpus*; *D*, samara of *Hiptage*.

(2) **Achene** (FIG. 165B). An achene is a small, dry, one chambered and one-seeded fruit developing from a superior, *monocarpellary*

ovary; but unlike the previous one, the pericarp of this fruit is free from the seed-coat. Achenes commonly develop as an aggregate from an apocarpous pistil, as in *Clematis* (see FIG. 173A) and *Naravelia* (FIG. 165B).

(3) **Cypsela** (see FIG. 172A). This is a dry, one-chambered and one-seeded fruit developing from an inferior, *bicarpellary* ovary with the pericarp and the seed-coat free, as in sunflower family or *Compositae*, e.g. sunflower, marigold, *Cosmos*, etc.

(4) **Nut.** This is a dry, one-chambered and one-seeded fruit developing from a superior, *bi-* or *polycarpellary* ovary, *with the pericarp hard and woody*, e.g. cashew-nut, water chestnut, chestnut, oak, beech, etc.

Coconuts and palmyra-palms are drupes because in them it is the endocarp that becomes hard and woody (and not the whole of the pericarp), and areca- or betel-nuts and date-palms are (one-seeded) berries because in them the pericarp is soft (fibrous in areca-nuts and pulpy in date-palms); it is the seed that is stony (and not the pericarp)

(5) **Samara** (FIG. 165 C-D). This is a dry, indehiscent, one- or two-seeded fruit developing from a superior, *bi-* or *tricarpellary* ovary, with flattened wing-like outgrowths, e.g. *Hiptage* (B. MADHABI-LATA; H. MADHU-LATA), *Hopea*, wood-oil tree (*Dipterocarpus*), maple (*Acer*), etc. In samara the wings always develop from the pericarp, and the fruit breaks into its component parts, each enclosing a seed. *Shorea* (B. & H. SAL) fruit is also a winged one; but here the wings are the dry, persistent sepals. Winged fruit of this nature is known as **samaroid**.

III. SPLITTING OR SCHIZOCARPIC FRUITS

(1) **Lomentum.** When the legume is constricted or partitioned between the seeds into a number of one-seeded parts, it is called a **lomentum**, as in gum tree (*Acacia*), sensitive plant, Indian laburnum (B. SHONDAL; H. AMALTAS), nicker bean (*Entada*; B. GILA), etc.

(2) **Cremocarp** (see FIG. 94). This is a dry, indehiscent, two-chambered fruit developing from an inferior, bicarpellary ovary. When ripe, the fruit splits apart into two indehiscent, one-sided pieces, called *mericarps*. The mericarps remain attached to the prolonged end (carpophore) of the axis. Cremocarp is the characteristic fruit of *Umbelliferae*, e.g. coriander, cumin, fennel or anise, carrot, etc.

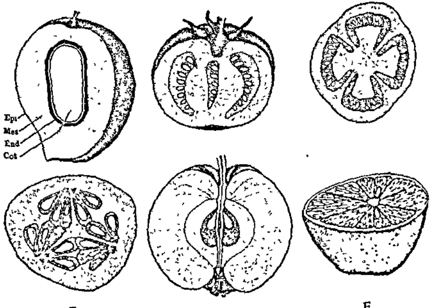
Other schizocarpic fruits are: **regma** of castor, **carcerule** of hollyhock, *Abutilon indicum* (B. PETARI; H. KANGHI), basil (*Ocimum*), and **double samara** of maple (*Acer*; see FIG. 169D).

IV. FLESHY FRUITS

(1) **Drupe** (FIG. 166A). This is a fleshy, one- or more-chambered and one- or more-seeded fruit developing from a *monocarpellary* or

syncarpous pistil, with the pericarp differentiated into the epicarp which forms the skin of the fruit, the mesocarp which is often fleshy and the *endocarp which is hard and stony*, and hence this fruit is also known as **stone-fruit**, e.g. mango, peach, plum, coconut-palm, palmyra-palm, country almond, etc.

A B



C D E

(2) **Bacca or Berry** (FIG. 166B). This is a superior (sometimes inferior), indehiscent, usually many-seeded, fleshy or pulpy *fruit* developing from a *single carpel* or more commonly *from a syncarpous* pistil, with axile or parietal placentation, e.g. tomato, gooseberry, grapes, brinjal, plantain, guava, papaw, etc. In berry the seeds at first remain attached to the placentae, but afterwards they separate from them (placentae) and lie free in the pulp. *Sometimes* a one-seeded berry, e.g. date-palm, *Artabotrys* (B. & H. KANTALI-CHAMPA) etc., can be found. Epicarp, mesocarp and endocarp may be *also* distinguished in such a berry, but it differs from the drupe in having *no stony endocarp*.

(3) **Pepo** (FIG. 166C). This is also a fleshy or pulpy, many-seeded

(4) Pome (FIG. 166D). This is an inferior, two- or more-celled, fleshy, *syncarpous* fruit surrounded by the thalamus. The fleshy edible part is composed of the thalamus, while the actual fruit lies within. Examples are found in apple and pear.

(5) Hesperidium (FIG. 166E). This is a superior, many-celled, fleshy fruit developing from a *syncarpous* pistil with axile placentation. Here the endocarp projects inwards forming distinct chambers, and the epicarp and the mesocarp, fused together, form the loose or tight skin (rind) of the fruit, e.g. orange, pummelo, lemon, etc.

B. Aggregate Fruits. An aggregate fruit is a collection of simple fruits (or fruitlets) developing from the apocarpous pistil (free carpels) of a flower. An aggregate of simple fruits borne by a single flower is otherwise known as an 'etaerio', and the common forms of etaerios are: (1) an **etaerio of follicles**, as in madar and periwinkle (with two follicles), in larkspur and aconite (with three follicles), and in *Michelia* (with numerous follicles); (2) an **etaerio of achenes**, as in *Clematis* and *Naravelia*, strawberry, rose and lotus; (3) an **etaerio of drupes**, as in raspberry (*Rubus*), with small drupes or drupels (also called drupelets) remaining aggregated together on a fleshy thalamus; (4) an **etaerio of berries**, as in custard-apple and bullock's heart, where the berries lie embedded in the fleshy thalamus; while in *Artabotrys* (B. & H. KANTALI-CHAMPA) and *Polyalthia* (B. DEBDARU; H. DEVADARU OR ASHOK) the berries are distinct and separate.

C. Multiple or Composite Fruits. A multiple or composite fruit is that which develops from a number of flowers juxtaposed together, or in other words, from an inflorescence. Such a fruit is otherwise known as an *infructescence.*

(1) Sorosis (see FIG. III/62). This is a multiple fruit developing from a spike or spadix. The flowers fuse together by their succulent sepals and at the same time the axis bearing them grows and becomes fleshy or woody, and as a result the whole inflorescence forms into a compact mass, e.g. pineapple, screwpine and jack-fruit. Mulberry is also a sorosis, with the fleshy part made of loosely attached sepals.

(2) Syconus (see FIG. 135). The syconus develops from a hollow, pear-shaped, fleshy receptacle which encloses a number of minute male and female flowers. The receptacle grows, becomes fleshy and forms the so-called fruit. It really encloses a number of true fruits or achenes which develop from the female flowers lying within the receptacle at its base, e.g. fig, banyan, peepul, etc.

Some Common Fruits and their Edible Parts. Apple (pome)—fleshy thalamus. Banana (berry)—mesocarp and endocarp. Cashew-nut (nut)—peduncle and cotyledons. Coconut-palm (fibrous drupe)—endosperm. Cucumber (pepo)—mesocarp, endocarp and placentae. Custard-apple (etaerio of berries)—fleshy pericarp of individual berries. Date-palm (1-seeded berry)—pericarp. *Dillenia* (special)—accrescent calyx. Fig (syconus)—fleshy receptacle. Jack (sorosis)—bracts,

perianth and seeds. **Grape** (berry)—pericarp and placentae. **Guava** (berry)—thalamus and pericarp. **Indian plum** (drupe)—mesocarp including epicarp. **Litchi** (1-seeded nut)—fleshy aril. **Maize, oat, rice** and **wheat** (*caryopsis*)—starchy endosperm. **Mango** (drupe)—mesocarp. **Melon** (pepo)—mesocarp. **Orange** (hesperidium)—juicy placental hairs. **Palmyra-palm** (fibrous drupe)—mesocarp. **Papaw** (berry)—mesocarp. **Pea** (legume)—cotyledons. **Pear** (pome)—fleshy thalamus. **Pineapple** (sorosis)—outer portion of receptacle, bracts and perianth. **Pomegranate** (special)—juicy outer coat of the seed. **Pummelo** or **shaddock** (hesperidium)—juicy placental hairs. **Strawberry** (etaerio of achenes)—succulent thalamus. **Tomato** (berry)—pericarp and placentae. **Wood-apple** (special)—inner endocarp and placentae.

Chapter 11 DISPERSAL OF SEEDS AND FRUITS

If seeds and fruits fall directly underneath the mother plant and the [illegible] of its [illegible]
of their r[illegible]
of them. [illegible]
to the att[illegible] devices for [illegible]
extinct is reduced to a minimum.

1. **Seeds and Fruits dispersed by Wind.** Seeds and fruits have various adaptations which help them to be carried away by the wind to a shorter or longer distance from the parent plant.

FIG. 167. Winged Seeds. *A*, *Oroxylon*; *B*, *Cinchona*; *C*, *Stereospermum*; *D*, *Lagerstroemia*.

(1) **Wings.** Seeds and fruits of many plants develop one or more appendages in the form of thin flat membranous wings, and the former also are light and dry; these devices help them to float in the air and facilitate their dispersion by wind. Thus we find that seeds of *Oroxylon* (B. SONA; H. ARLU—FIG. 167A), *Cinchona* (FIG. 167B), *Stereospermum* (B. PARULI; H. PARRAL—FIG. 167C), *Lagerstroemia* (B. & H. JARUL—FIG. 167D), drumstick (*Moringa*; B. SAJINA; H. SAINJNA—FIG. 168A) and *Tecoma* are provided with wings. Similarly many fruits are also provided with one or more wings for the same purpose, e.g. yam (*Dioscorea*; FIG. 168B), ash (*Fraxinus*; FIG. 169A), *Terminalia myriocarpa* (B. HOLOK—FIG. 169B), *Hopea* (FIG. 169C), maple (*Acer*—FIG. 169D), wood-oil tree (*Dipterocarpus*; B. & H. GARJAN—FIG. 170A), *Hiptage* (B. MADHABI-LATA; H. MADHU-LATA—FIG. 170B) and *Shorea* (B. & H. SAL—FIG. 170C).

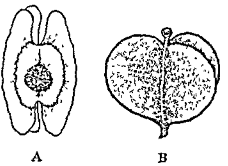


FIG. 168. *A*, winged seed of drumstick (*Moringa*); *B*, winged fruit of yam (*Dioscorea*).

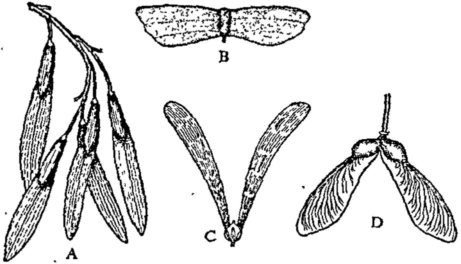


FIG. 169. Winged Fruits. *A*, ash (*Fraxinus*); *B*, *Terminalia myriocarpa*; *C*, *Hopea*; *D*, maple (*Acer*).

(2) **Parachute Mechanism.** In many plants of *Compositae* the calyx is modified into hair-like structures known as pappus (FIG. 172A). This pappus is persistent in the fruit, and opens out in an umbrella-like fashion. As the fruit gets detached from the parent plant the pappus acts like a parachute and helps it to float in the air. The fruit is often seen being carried by air current to a great distance.

(3) **Censer Mechanism.** Seeds of certain plants can only be scattered by the wind after the dehiscence of the fruit; in such cases the

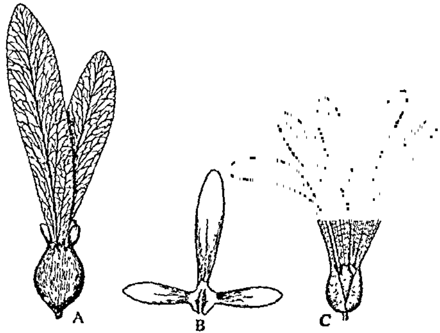


FIG. 170. Winged Fruits (*contd.*). *A*, *Dipterocarpus*; *B*, *Hiptage*. *C*, *Shorea*

seeds are often not discharged from the fruit unless the latter is shaken by the wind. Thus in poppy, prickly poppy (*Argemone*), bath

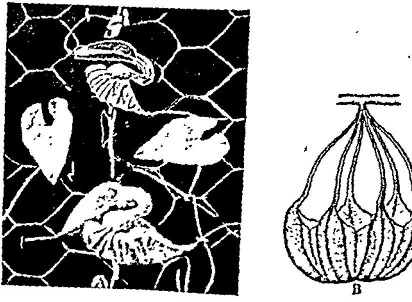


FIG. 171. *A*, pelican flower (*Aristolochia*) with duck-shaped flowers; *B*, a fruit of the same like a hanging basket.

sponge, pelican flower (*Aristolochia gigas*; B. HANSA-LATA—FIG. 171), etc., the fruit dehisces, and then, when it is disturbed by the wind, the seeds are thrown out.

(4) **Hairs.** Seeds of madar (*Calotropis*; FIG. 172B), blood flower (*Asclepias*), *Holarrhena* (B. KURCHI; H. KARCHI), devil tree (*Alstonia*;

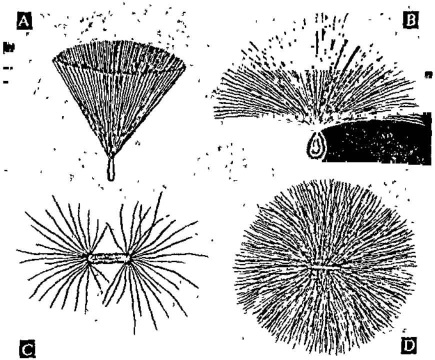


FIG. 172. Pappus and Hairy Seeds. *A*, pappus of a *Compositae* fruit; *B*, hairy seed of madar (*Calotropis*); *C*, ditto of devil tree (*Alstonia*); *D*, ditto of cotton.

FIG. 172C) and cotton (FIG. 172D) are provided with hairs either in 1 or 2 tufts or all over their body. These hairs aid the distribution of seeds by the wind.

(5) **Persistent Styles.** In *Clematis* (FIG. 173A) and *Naravelia* (FIG. 173B) the styles are persistent and very feathery. The fruits are thus easily carried away by the wind.

(6) **Light Seeds and Fruits.** Some seeds and fruits are so light and minute in size that they may easily be carried away by the gentlest breeze. Orchids

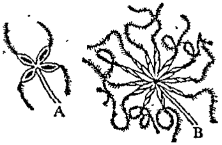


FIG. 173. Persistent styles. *A*, fruits of *Clematis*; B, fruits of *Naravelia*.

bear the smallest seeds in the vegetable kingdom. In them millions of dust-like seeds are produced in a capsule. Seeds (fruits) of some grasses are also very small and light. Seeds of *Cinchona* (the quinine-yielding plant) are also very small, thin and extremely light, and further provided with a membranous wing (see FIG. 167B). There are about 2,500 seeds to a gramme. In *Bucklandia*, a handsome tree of the Khasi Hills, about 250 seeds, mostly winged, weigh a gramme. In *Terminalia myriocarpa* (HOLOK), a timber tree of Assam, about 180 seeds weigh a gramme.

2. Seeds and Fruits dispersed by Water. Seeds and fruits to be dispersed by water usually develop floating devices in the form of spongy or fibrous outer coats. The fibrous fruit of coconut is capable of floating long distances in the sea without suffering any injury. Hence coconut forms a characteristic vegetation of sea-coasts and marine islands. The same is the case with double coconut (*Lodoicea*; FIG. 174), a native of Seychelles. The plant bears the largest seeds, and the fruit takes about ten years to ripen. In lotus (see FIG. 93C) the spongy thalamus, bearing the fruits on its hemispheric top, floats bodily about in water, and drifts according to the currents of the water or wind. Sometimes seeds are small and light, and can float on water, e.g. seeds of water lily; these are also provided with an *aril* which encloses air. Seeds and fruits of river-side plants are regularly carried downstream by currents.

FIG. 174. Double coconut seed (*Lodoicea*).

3. Seeds dispersed by Explosive Fruits. Many fruits burst with a sudden jerk, with the result that seeds are scattered a few yards away from the parent plant. Common examples of explosive fruits are afforded by balsam, wood-sorrel, night jasmine, castor, etc. Ripe fruits of balsam, when touched, burst suddenly. The valves roll up inwards and the seeds are ejected with great force and scattered in all directions. Many plants of *Acanthaceae* bear explosive fruits which under wet or dry conditions dehisce suddenly from the apex to the base and throw out the seeds with some force. In many such cases the seeds are further provided with jaculators (curved hooks) which straighten out suddenly and help in their ejectment. Thus the dry fruits of *Ruellia* (FIG. 175) coming in contact with water, soaked after a shower of rain, burst suddenly with a noise into two valves and the seeds are scattered on all sides. Similarly the mature fruits of *Andrographis*, *Barleria*, *Acanthus*, etc., burst suddenly when the air is dry, and the seeds are ejected. The cracking sound of the bursting

fruits of *Phlox* and *Barleria* is distinctly audible on a bright sunny day.

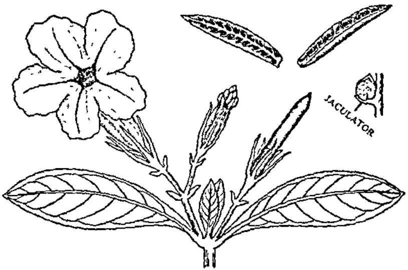


FIG. 175. *Ruellia tuberosa*; note the explosive fruit.

A very interesting example of bursting fruits is found in camel's foot climber (*Bauhinia vahlii*; B. CHEHUR or LATA-KANCHAN; H. CHAMBULI). Its long pods, sometimes more than 30 centimetres in length, explode violently with a loud noise, scattering the seeds in all directions (FIG. 176).

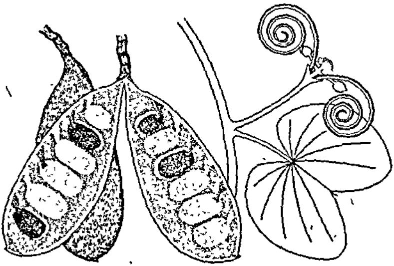


FIG. 176. *Bauhinia vahlii*; note the explosive fruit.

4. Seeds and Fruits dispersed by Animals. Many seeds and fruits are provided with hooks, burs, barbs, spines, stiff hairs and sticky glands

on their surface, by means of which they adhere to the body of woolly animals as well as to the clothing of mankind. They easily stick to the clothing of unwary persons and often enjoy a distant journey through them. Thus *Xanthium* and *Urena* (FIG. 177 A-B) are

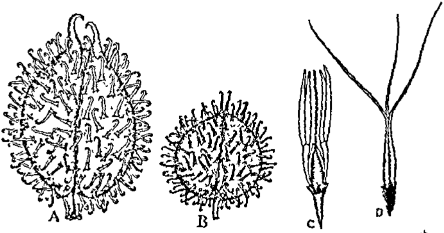


FIG. 177. *A*, fruit of *Xanthium* with curved hooks; *B*, fruit of *Urena* with curved hooks; *C*, spikelet of love thorn with stiff hairs; *D*, seed (fruit) of spear grass with stiff hairs.

covered with numerous curved hooks. Spikelets of love thorn (*Chrysopogon*; FIG. 177C) and seeds (fruits) of spear grass (*Aristida*; FIG. 177D) are provided with a cluster of minute stiff hairs pointing upwards. For the same purpose the fruits of *Boerhaavia* (FIG. 178A) and *Plumbago* have sticky glands on their body. Flower clusters of *Pupalia* (FIG. 178B) bear stellate hooked bristles which spread outwards. The seed of tiger's nail (*Martynia*; B. BAGH-NAKH; H. SHERNI- FIG. 178C.) is provided with two sharp-pointed, and bent hooks for effective dispersion by woolly animals. In *Tribulus* (B. GOKHRI-KANTA; H. GOKHRU) there are sharp rigid spines on the fruit.

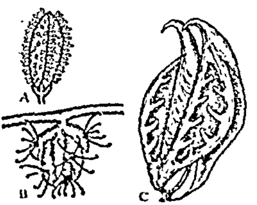


FIG. 178. *A*, fruit of *Boerhaavia* with sticky glands (see also FIG. II/38B); *B*, flowers of *Pupalia* with hooked bristles; *C*, fruit of tiger's nail (*Martynia*) with a pair of sharp, curved hooks.

Seeds of many fleshy fruits are widely distributed by birds. They feed upon the pulpy fruits such as guava, grape, fig, etc., and pass out the undigested seeds with the faeces; the seeds then germinate. Sticky seeds, as of mistletoe (see FIG. 23), are left by birds on branches

of trees. Jackals feed upon dates, plums, etc., and the seeds germinate after passing through their alimentary canal. Bats and squirrels are also useful agents for the dispersal of seeds and fruits. There is always wide distribution of seeds and fruits through the agency of mankind.

and ferns. In 1905 the term meiosis was applied to reduction division by Farmer and Moore. Polyploidy and aneuploidy were discovered between 1912 and 1927 —triploidy ($3n$) by Miss Lutz in 1912, tetraploidy ($4n$) by Digby in the same year, pentaploidy ($5n$) by Nawaschin in 1925 and 1927, aneuploidy ($2n-1$, $2n+1$, $4n+1$) by Tackholm in 1922.

Further important early work on plant anatomy may only be just mentioned: Sanio's work on the activity of the cambium and the formation of the secondary tissues (1863), De Bary's work on comparative anatomy (1877) and on tissue systems (1884), Jeffrey's theory of stelar structure (1868), Nageli's theory of single-celled apical meristem (1858), Hanstein's histogen theory of apical meristem (1868), Schmidt's tunica-corpus theory (1924), Haberlandt's work on physiological plant anatomy (1884), etc.

Cell Structure. Cells are the fundamental structural and functional units that the plant body or the animal body is composed of. A plant cell may be defined as a unit or independent, tiny or microscopic mass of protoplasm enclosing in it a denser spherical or oval body, called the nucleus, and bounded by a distinct wall, called the cell-wall. Protoplasm and nucleus are living, while the cell-wall is non-living, the latter having been formed by the protoplasm primarily for its own protection. The living parts of a cell (protoplasm, nucleus and other living bodies) together constitute the protoplast of the cell—a collective and convenient term introduced by Hanstein in 1880. A plant cell thus consists of a protoplast (representing the living parts) and a cell-wall (forming a non-living framework round the protoplast to maintain its shape and firmness and to afford necessary protection).

Cells vary widely in shapes and sizes. In shape they may commonly be spherical, oval, polygonal, rectangular or considerably elongated. When young, they are often spherical or of like nature. Usually they are very minute in size invisible to the naked eye. The average size of fully developed rounded or polygonal cells varies between 1/10th and 1/100th of a millimetre. Sometimes, as in fleshy fruits and pith, they may be as big as 1 mm. or even bigger, or as small as 1/200th mm. or even smaller. Among the known cells bacteria are the smallest, usually ranging between 1/100th and 1/1,000th mm. or even smaller. Still smaller in size are the viruses which defy microscopic observation. Fibrous cells are considerably elongated; they chiefly vary in length from 1 to 3 mm., but in woody stems they may often be as big as 6 mm. or even 8 mm. In some fibre-yielding plants such as flax, hemp and rhea the fibrous cells may grow to a length to 20 to 550 mm. Still larger cells are the latex cells.

The Protoplast

The protoplast is the living unit—actually the physiological unit—of a cell, while the protoplasm is the essential living material that com-

prises the different parts of it (the protoplast). Protoplasm is the only substance that is endowed with life and, therefore, plants and animals containing this substance in their body are regarded as living. As the protoplasm dies the cell ceases to perform any function for the plant or the animal, and the latter (plant or animal) as a whole then dies. Protoplasm is fittingly described as the *physical basis of life*. As the protoplast as a whole has to perform manifold functions of a cell, such as manufacture of food, nutrition, growth, respiration, reproduction, etc., it is differentiated into distinct living (protoplasmic) bodies: (1) cytoplasm, (2) nucleus, and in special cells (3) plastids. These are only masses of protoplasm differentiated into distinct bodies (FIG. 1C) to perform specialized functions. It must, however, be noted that these living bodies are never newly formed in the cells but always develop from pre-existing ones and that one kind of living body cannot give rise to another kind.

1. **Cytoplasm.** The protoplasmic mass of a cell leaving out the nucleus and the plastids is otherwise called cell-protoplasm or cytoplasm.

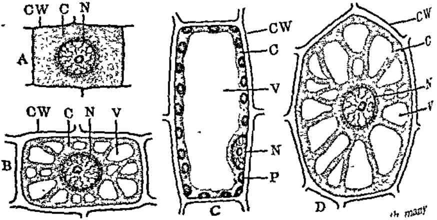


FIG. 1. Plant ... small vacuoles; ... many vacuoles. ... P, plastid ...

plasm. When the cell is young the cytoplasm fills in the space between the cell-wall and the nucleus. The surface of the cytoplasm forms into an extremely thin and delicate membrane known as the plasma membrane or ectoplasm. This plasma membrane is also hyaline but non-granular and somewhat firmer in consistency than the rest of the cytoplasm, and it lies adpressed against the cell-wall. This is a very important layer controlling the entrance and exit of substances into the cell and out of it. The inner granular mass of the cytoplasm is often called endoplasm. Besides, it is often seen that the cytoplasm encloses numerous minute granules whose nature is obscure; these are known as the *microsomes*. When the cell is very young (FIG. 1A) a

remains completely filled with the cytoplasm, but as the cell increases in size (FIG. 1B) it develops a number of small non-protoplasmic cavities of varying sizes, called vacuoles (*vacuus*, empty). With further growth of the cell all these small vacuoles begin to fuse together and finally in a mature cell they form one big vacuole which occupies the major part of the cell-cavity, and then the cytoplasm is pushed outwards as a thin layer alongside the cell-wall, with the nucleus and the plastids lying embedded in this layer (FIG. 1C). Or sometimes, instead of one, a number of comparatively small vacuoles persist in a mature cell, and then the cytoplasm occurs as delicate strands around those vacuoles and also as a very thin layer lining up with the cell-wall; these strands are seen to radiate from around the nucleus, often suspending it in the cavity of the cell (FIG. 1D). The vacuole is filled with a watery solution known as the cell-sap. In the young condition of the cell the cell-sap permeates the cytoplasm. Dissolved in the cell-sap, or lying in a state of suspension in it, there occur various chemical compounds. The vacuole is thus regarded as the storehouse of water, mineral or inorganic salts, certain organic substances (mainly soluble food materials), etc. The layer of cytoplasm in contact with the vacuole and surrounding it as a membrane is known as the **vacuole membrane or tonoplasm.**

Physical Nature of Protoplasm. Protoplasm is a transparent, foamy or granular, slimy, semi-fluid substance, somewhat like the white of an egg. It is never homogeneous but contains granules of varying shapes and sizes, and, therefore, it looks finely granular under the microscope. Although often semi-fluid it may be fluid or viscous. Its occurrence completely fills up the cavity of the young cell, but in a mature cell it may occur as a thin layer against the cell-wall (FIG. 1C) or it may occur as delicate strands around the vacuoles (FIG. 1D), as described above. In its *active* state the protoplasm remains saturated with water which makes up 75-90 per cent of the content. With decreasing water content its vital activity diminishes and gradually comes to a standstill, as in dry seeds. Protoplasm coagulates on heating, and when killed it loses its transparency.

Structure. Protoplasm, as it works in the cell, undergoes dynamic physical changes and, therefore, its ultimate structure cannot be known with any amount of certainty. So from time to time its structure has been variously expressed as (*a*) fibrillar consisting of interlacing fine fibres or fibrils (Flemming, 1882), (*b*) alveolar or foamy consisting of a froth of minute bubbles (Butschli, 1878), and (*c*) granular consisting of fine grains or granules more or less uniformly dispersed throughout the protoplasm (Hanstein, about 1886).

Protoplasm responds to the action of external stimuli such as needle- or pin-prick, electric shock, application of particular chemicals, sudden variation of temperature or of light, etc. On stimulation the protoplasm contracts but expands again when the stimulating agent is

removed. This 'contractility' involving both contraction and expansion, first demonstrated by Kühne in 1864 in the staminal hair of spiderwort, is an inherent power of protoplasm.

Protoplasm is semi-permeable in nature, i.e. it allows only certain substances and not all to enter its body. This property is, however, lost when the protoplasm is killed.

Under normal conditions the protoplasm of a living cell is in a state of slow but constant motion. In many cases, however, it shows distinct movements of different kinds (see pp. 135-6).

Chemical Nature of Protoplasm. Chemically protoplasm is a highly complex mixture of a variety of chemical substances of which proteins are the chief. The exact chemical composition of the living protoplasm cannot be determined because any attempt to analyse it kills it outright with some unknown changes in it. Besides, it undergoes continual changes and its composition is not, therefore, constant. Further, protoplasm always encloses many foreign substances

ur (S), phosphorus potassium (K), iron zinc

the protoplasm contains the following: proteins—40-60%, ... substances (true fats and lipids, particularly lecithin)—12-14%; carbohydrates—12-14%; and inorganic salts—5-7%.

semi-solid. In the case of protoplasm the dispersion medium is water

are unstable settling down under slight chemical or physical change. A colloid

cannot change from one state to the other. The colloidal system of protoplasm believed to be responsible for its various life-processes.

Tests. (*a*) Iodine solution stains protoplasm brownish yellow. (*b*) Dilute caustic

potash dissolves it. (*c*) Millon's reagent (nitrate of mercury) stains it brick-red; the reaction is hastened by heating.

Movements of Protoplasm. Protoplasm shows movements of different kinds. Naked masses of protoplasm, not enclosed by the cell-wall, show two kinds of movement—**ciliary** and **amoeboid**. The protoplasm, enclosed by the cell-wall, shows a streaming movement within it, which is spoken of as *cyclosis*. Cyclosis is of two kinds—**rotation** and **circulation**.

(1) **Ciliary Movement** (FIG. 2A) is the *swimming* movement of free, minute, protoplasmic bodies such as the zoospores of many algae

A B

FIG. 2. Movements of Protoplasm. *A*, ciliary movement; *B*, amoeboid movement.

and fungi, bacteria, antherozoids of mosses and ferns, etc., provided with one or more special organs of motion in the form of whip-like structures, called cilia or flagella. By the vibration of these cilia such

by the protrusion of one or more parts of its body in the form of false feet or pseudopodia (*pseudos*, false; *pod*-, foot) and their withdrawal at the next moment, very much like the animalcule *Amoeba*. Cell-wall being absent, the protoplasmic mass has no definite shape, and is capable of engulfing solid particles of food. Amoeboid movement is exhibited by many slime fungi, zoospores of certain fungi, *Euglena*—a unicellular alga (see FIG. V/4C), etc.

(3) **Rotation** (FIG. 3A). When the protoplasm moves or streams within a cell alongside the cell-wall, clockwise or anti-clockwise, round a large central vacuole, the movement is expressed as rotation. The direction of movement is constant so far as a particular cell is concerned. As the protoplasm rotates, it carries in its current the nucleus and the plastids. Rotation is distinctly seen in *Vallisneria*, *Hydrilla*, *Chara* and *Nitella*, and also in many other aquatic plants.

(4) **Circulation** (FIG. 3B). When the protoplasm moves or *streams* in different directions within a cell round a number of small vacuoles,

of delicate strands; each strand then moves round one or more vacuoles and finally comes back to the nucleus. Circulation is very

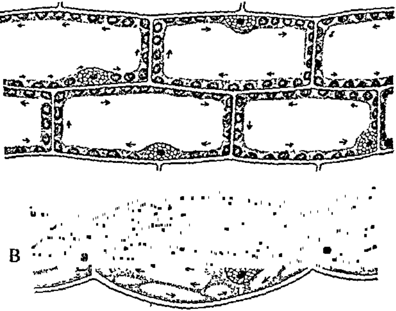


FIG. 3. Movements of Protoplasm (*contd.*). *A*, rotation in the leaf of *Vallisneria*; *B*, circulation in the staminal hair of *Commelina obliqua*.

distinctly seen in the purplish staminal hairs of *Commelina obliqua* (B. JATA-KANSHIRA; H. KANJURA). It is also seen in the staminal hairs of spiderwort (*Tradescantia*), in the young shoot-hairs of gourd, elephant ear plant (*Begonia*) and in many other land plants.

2. **Nucleus.** Embedded in the cytoplasm there is a specialized protoplasmic body, usually spherical or oval in shape and much denser than the cytoplasm itself; this is the nucleus. Its shape depends to some extent on the nature of the cell in which it occurs. In the young cell it occupies a median position and is almost always spherical or oval; but in the long cell it may become correspondingly elongated.

...

rial. Nuclei may vary widely in size from 1-500 microns (μ). The usual size, however, is 5-25 microns (μ). A nucleus can never be

newly formed, but multiplies in number by the division of the preexisting one.

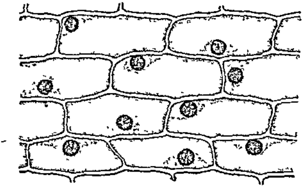


FIG. 4. Cellular structure and nuceli in onion scale.

Structure. Each nucleus (FIG. 5) is surrounded by a thin, transparent membrane known as (1) the **nuclear membrane** which separates the nucleus from the surrounding cytoplasm. The shape of the nucleus depends partly on it. Within the membrane, completely filling up the space, there is a dense but clear mass of protoplasm known as (2) **the nuclear sap or nucleoplasm or karyolymph.** Suspended in the nucleoplasm there are numerous, fine, crooked threads, loosely connected here and there, forming a sort of network, called (3) **the nuclear reticulum or chromatin network.** The threads are made of a substance known as **chromatin** or **nuclein** which is strongly stainable. The chromatin is a nucleoprotein which is a phosphorus-containing protein. One or more highly refractive, very minute and usually spherical bodies, much denser than the nucleoplasm, also occur in the nucleus; these are known as (4) **the nucleoli.**

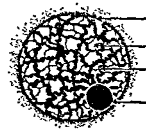


FIG. 5. Nuclear structure.

Nucleoli remain attached to certain chromosomes in their particular regions. They are, therefore, regarded as parts of those chromosomes. Nucleoli act as reservoirs of nucleoproteins which become converted into proteins and nucleic acid during mitosis.

Chemical Composition. The chemical composition of the nucleus is more or less similar to that of the cytoplasm. It is composed of proteins and protein-like substances. It contains a material, known as *nuclein.* Chemically this nuclein is a nucleoprotein which contains phosphorus in addition to carbon, hydrogen, oxygen, nitrogen and sulphur. Nuclein is present in the reticulum, but not in the nucleoplasm. The nucleus is slightly alkaline.

(2) **Chloroplasts** (*chloros*, green). These are green plastids, their colour being due to the presence of a green *pigment* to which the name **chlorophyll** was given by Caventou in the year 1818; sometimes the green colour may be masked by other colours. Chloroplasts are only found in parts exposed to light; they occur abundantly in green leaves, and also to some extent in green parts of the shoot. They are mostly spherical or discoidal in shape, but in some bryophyta and algae they may assume peculiar forms. *Functions.* They work *only in the presence of sunlight* and perform some very important functions with the help of their chlorophyll. They absorb carbon dioxide from the air; manufacture sugar and starch from this carbon dioxide and the water absorbed from the soil; and liberate oxygen (by splitting the water) which escapes to the surrounding air.

Chlorophyll, as worked out by Willstatter and Stoll (1906), is a mixture of four different pigments, viz. chlorophyll *a* (blue-black), chlorophyll *b* (green-black), carotene (orange-red) and xanthophyll (yellow). *Chlorophyll a and chlorophyll b are associated with each other in the chloroplast, but carotene and xanthophyll may also occur without chloroplast in any part of the plant.* Chlorophyll as a whole can be easily extracted with alcohol, benzene, acetone, ether, or chloroform and the leaves then become colourless. The chlorophyll solution appears deep green in transmitted light, but blood-red in reflected light. This is the physical property of chlorophyll called *fluorescence*. A mixture of the two pigments—carotene and xanthophyll, which are always associated with chlorophyll, can be easily separated from the chlorophyll solution by shaking it with a small quantity of benzene and allowing the solution to settle for a few minutes; the benzene floats on the top (green solution) carrying chlorophyll, while alcohol settles at the bottom (yellow solution) retaining carotene and xanthophyll. Instead of benzene, ether or olive-oil may be used. Chlorophyll is not soluble in water, even under prolonged boiling. Chlorophyll forms about 8% of the dry weight of the chloroplast, while carotene and xanthophyll about 2%. *Functions.* It is definitely known that chlorophyll absorbs certain rays of light. It may also help in the chemical process involved in the manufacture of food by the chloroplasts. *Origin.* Chlorophyll has its origin in a colourless substance called *leucophyll*; the latter is first converted into protochlorophyll (or chlorophyllogen) which is finally transformed into chlorophyll in the presence of light.

Chemical composition of chlorophyll

Chlorophyll *a*	—$C_{55}H_{72}O_5N_4Mg$	Carotene	—$C_{40}H_{56}$
Chlorophyll *b*	—$C_{55}H_{70}O_6N_4Mg$	Xanthophyll	—$C_{40}H_{56}O_2$

(3) **Chromoplasts** (*chroma*, colour). These are variously coloured plastids—yellow, orange and red. They are mostly present in the petals of flowers and in fruits, and the colouring matters (pigments)

associated with them are **xanthophyll** (yellow) and **carotene** (orange-red). Various other colours are formed as a result of combinations of red, yellow and green. The function of pigments occurring in flowers is to attract insects for cross-pollination (see p. 93).

Carotenoids. A number of pigments—yellow, orange and sometimes red, are found in plants; these are collectively called carotenoids. They may be divided into two main groups—*carotenes* and xanthophylls. They are always associated with chlorophyll, but may also occur independently in any part of the plant body. They are not connected with photosynthesis. All carotenoids are insoluble in water but dissolve readily in ethyl ether. They are not easily destroyed by heat or light. A **carotene** is a hydro-carbon, i.e. it consists of carbon and hydrogen, its formula being $C_{40}H_{56}$. It is readily soluble in petroleum ether. A **xanthophyll** on the other hand is an oxidation product of carotene, i.e. it has oxygen in addition, its formula being $C_{40}H_{56}O_2$. It is readily soluble in ethyl alcohol but not in petroleum ether.

Colours of most violet or purple and blue flowers and also of many red and brown ones are, however, due to pigments—anthocyanins, *dissolved in the cell-sap*. Anthocyanins occur in flowers, in coloured roots, e.g. beet-root, and in coloured stems, e.g. balsam stem. They also occur in the variegated leaves of [illegible] sap is acid, and it is blue [illegible] reaction. There are various other pigments also in the plant body.

Other Cytoplasmic Bodies. (1) Centrosomes. These occur as minute granules near the nucleus of animal cells and in some lower plants such as algae (particularly brown algae) and fungi. They are not found in seed plants. *During nuclear division* the centrosome divides into two and these pass on to the two poles of the spindle forming the centres of cytoplasmic radiations—the 'asters'.

(2) Chondriosomes or Mitochondria. These are very small bodies present in the cytoplasm of nearly all plant and animal cells. In plant cells they were first discovered in 1897. They may occur in the form of rods, granules or filaments and are largely composed of protein and lipoid (a fatty substance). They have certain characteristic staining properties and can be demonstrated only after special treatments. There are diverse views regarding their structure and [illegible]. According to some investigators they are the starting points of the different types of plastids. They are also said to be connected with respiration and secretion of enzymes.

(3) Golgi Bodies. These occur as more or less conspicuous, net-like, small bodies in the cytoplasm as seen after a special method of preparation. They were first noted in animal cells and are more abundant in them than in plant cells. In

gland cells of animals golgi bodies are associated with secretions, but in plants their significance is still obscure.

The Cell-wall

The cell-wall is a constant feature of the plant-cell. An individual plant, however, begins life as a *naked* cell, i.e. the egg-cell, which is a prominent nucleus in a small mass of protoplasm, but with no cell-wall. Protoplasm being a very soft and delicate substance, its primary need is self-protection. For this purpose it forms a wall round itself. The cell-wall is always the secretion product of the protoplasm, i.e. to form it the protoplasm begins to secrete minute granules on the surface of its body. As more granules are secreted they fuse together, resulting in a complete but thin and delicate wall, i.e. the **cell-wall**. It forms a framework round the protoplasm, maintains its shape, affords protection, and finally gives rigidity to the plant body as a whole. *Physically the wall is composed of very thin microscopic* lamellae, extending tangentially around it.

Growth of the Cell-wall. The cell-wall, when first formed, is a very thin and delicate layer. As the cell grows we find changes—both chemical and physical—in the cell-wall. Physical changes are: growth of the wall in surface extent and growth of it in thickness. (1) Growth of the cell-wall in surface extent, i.e. its increase in size, takes place in the early stage of the cell and is due to stretching of the cell-wall in one or more directions accompanied by an intercalation, within the original wall, of new solid particles secreted by the protoplasm. This method is known as **growth by intussusception** (Nageli's theory). (2) Growth of the cell-wall in thickness, on the other hand, is mainly due to deposition of definite thin plates or layers by the protoplasm, one after another, on the inner surface of the original wall. This method is known as **growth by apposition** (Strasburger's theory). When the cell-wall becomes considerably thickened, it shows a *stratified* appearance, that is, the appearance of a number of strata or layers arranged in a series. The original cell-wall between two contiguous cells can still be recognized under the microscope. This original or middle wall is known as the **middle lamella** (FIG. 6). It consists of a substance, called calcium pectate. It is further seen that the protoplasm of one cell is connected with that of the neighbouring one by fine protoplasmic threads or strands passing through extremely minute pits (not visible under the microscope) that develop in the cell-wall. Each of these protoplasmic strands is called a **plasmodesma** (pl. plasmodesmata; FIG. 6) first discovered by Tangl in 1879. Later work showed that transmission of stimuli from cell to cell and translocation of food material in the storage tissues take place through the strands. It must be noted that the cell-wall grows in thickness in

stages. The cell-wall originally formed by the protoplasm as a very thin layer continuous with the protoplasm and made of pectose is called the *primary wall*. The primary wall common to two contiguous cells, evidently formed by both of them, is called the middle lamella, as already stated. Fresh layers laid down against the primary wall by the process of apposition form the *secondary wall*. It consists of pectose and cellulose. A *tertiary wall* made of pure cellulose is soon laid down against the secondary wall. The secondary and tertiary walls cannot, however, always be distinguished, and are together known as the secondary thickening. It may finally become lignified.

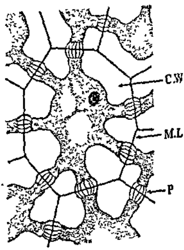


FIG. 6. Cells from the endosperm of date seed. *C.W*, cell-wall (hemicellulose, see p. 151); *M.L*, middle lamella; *P*, plasmodesma.

Thickening of the Cell-wall (FIG. 7). The secondary thickening of the cell-wall may be more or less uniform all round the cell, almost always showing a stratified appearance. But in those cells which have ultimately to grow up into vessels (see p. 174) and tracheids (see

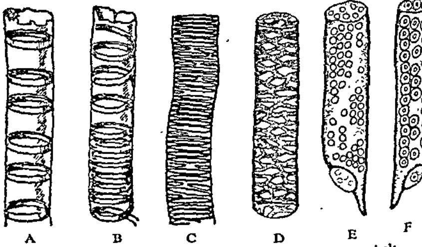


FIG. 7. Thickening of the Cell-wall. *A*, annular; *B*, spiral; *C*, scalariform; *D*, reticulate; *E*, pitted (with simple pits); *F*, pitted (with bordered pits).

ening takes place only after the aforesaid elements have grown and attained their full dimensions. The thickening being localized, a portion of the wall may remain unthickened. The patterns of thickening may be as follows:

(1) **Annular or ring-like** (A), when the deposit of lignin is in the form of rings which are placed, one a little above the other, in the interior of the original cell-wall, the remaining portion of the wall being unthickened.

(2) **Spiral** (B), when the thickening takes the form of a spiral band.

(3) **Scalariform or ladder-like** (C), when the thickening matter or lignin is deposited transversely in the form of rods or rungs of a ladder, and hence the name scalariform or ladder-like. Unthickened portions of the wall appear as transverse pits, while the thickened spaces between them give a ladder-like appearance to the wall.

(4) **Reticulate or netted** (D), when the thickening takes the form of a network, evidently leaving a number of irregular unthickened spaces in the wall.

(5) **Pitted** (E-F), when the whole inner surface of the cell-wall is more or less uniformly thickened, leaving here and there some small unthickened areas or cavities. These unthickened areas are called pits, and are of two kinds, viz. (*a*) **simple pits** and (*b*) **bordered pits**. Pits are formed in pairs lying against each other on the opposite sides of the wall. The portion of the original wall separating the two opposing pits is called the *closing membrane*. The closing membrane in the bordered pits shows a slight swelling or thickening in the middle, called **torus** (FIG. 10B-C). When the area of a pit is uniform throughout its whole depth, it forms a simple pit (FIGS. 8-9); and when this area is unequal, broader towards the wall and narrower towards the cavity of the cell, more or less like a funnel without the stem, it forms a bordered pit (FIG. 10). In the bordered pit the adjoining thickening matter of the wall grows inwards and arches over the pit from all sides forming an overhanging border, and hence the name 'bordered' pit. In surface view the simple pit may be circular, oval, polygonal, elongated or somewhat irregular; while the bordered pit is often circular or oval. Pits are areas through which diffusion of liquids takes place more easily. In bordered pits this diffusion is regulated to a great extent by the torus which, when pushed from one side, blocks the pit (FIG. 10C). Through simple pits, contained in the living cells, diffusion of protoplasm also takes

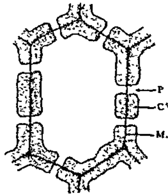


FIG. 8. Simple Pits. A cell in section showing simple pits in its wall; *P*, pit; *C.W*, cell-wall; *M.L*, middle lamella.

place. Bordered pits are abundantly found in the tracheids of conifers (e.g. pine; FIGS. 11 & 33) and in the vessels of angiosperms; simple

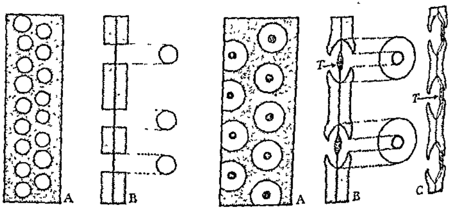


FIG. 9. FIG. 10.

FIG. 9. Simple pits. *A*, cell-wall with simple pits (surface view); *B*, the same (sectional view). FIG. 10. Bordered pits. *A*, cell-wall with bordered pits (surface view); *B*, the same (sectional view); *C*, the same showing the torus (*T*) pushed against the pit blocking it.

pits are also found in them, but they are more frequent in some of the living cells, and occur largely in the wood parenchyma, medullary rays, phloem parenchyma, companion cells, etc. Fibres are often provided with simple oblique pits and sometimes also with bordered pits, and stone cells with simple, branched pits.

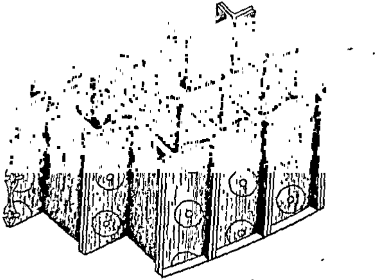


FIG. 11. Tracheids with bordered pits of pine stem (diagrammatic). *Redrawn after Fig. 86 in* Introduction to Plant Anatomy *by A. J. Eames and L. H. MacDaniels by permission of McGraw-Hill Book Company. Copyright 1925.*

Chemical Nature of the Cell-wall. The chemical substances which enter into the composition of the cell-wall are mainly pectin, cellulose, lignin, cutin, suberin and mucilage. Many mineral matters may also be introduced into the cell-wall.

Cellulose. The wall of the young cell is composed of a substance called cellulose; associated with it are other substances, of which pectic compounds are conspicuous. When first formed the wall is fundamentally composed of pectin which soon becomes converted into insoluble pectate of calcium, as in the middle lamella. Pectin acts as a cementing material holding together the cells of the plant body very much like cement in a brick wall. Later both pectin and cellulose form the wall substance, and later still pure cellulose is secreted by the protoplasm. Regarding the origin of cellulose Sponsler is strongly of opinion from his X-ray studies in 1929 that it is directly transformed from glucose in the presence of protoplasm. Cellulose is universally present in the cell-walls of all the soft parts of plants with the exception of fungi. It is a soft, elastic and transparent substance, and is readily permeable to water. Walls made up of cellulose are usually thin, and the cells living, containing protoplasm. Chemically, it is a carbohydrate represented by the formula $(C_6H_{10}O_5)n$, the value of n not being known. Cellulose is a very important substance. It is used as food by herbivorous animals; it cannot, however, be digested by human beings. Articles like paper, gun-cotton, celluloid and artificial silk are prepared from it. Seed fibres such as cotton and kapok are made of pure cellulose, while bast fibres and woody tissues are predominantly made of lignin associated with cellulose (together called lignocellulose).

Pectic compounds occur in plants in three forms: insoluble pectose (protopectin), soluble pectin and insoluble pectic acid. One form may change into the other in the plant body. Pectin swells in water into mucilage, as the gelatinous sheath of many algae. It is present in many fruits and vegetables, and is responsible for the setting of jellies made from fruits. Pectin, present in the cell-walls, acts as a binding or cementing material holding together cells of the plant body. A large proportion of pectin in the cell-wall makes it elastic, as in collenchyma.

CHEMICAL CHANGES IN THE CELL-WALL

1. **Lignification.** This is due to the deposit of layers of lignin in the original cellulose wall, or the cellulose may be converted into lignin. In either case the whole wall may be lignified, or lignification may only be partial with certain amount of cellulose (lignocellulose) associated with it. Lignin is a hard and chemically complex substance. It is found in the hard and woody tissues of plants. Lignified cells are usually thick-walled and dead. Although hard, lignin is permeable to water. Bast fibres, tracheids and wood vessels are common ligni-

fied structures. The function of lignified tissues is mechanical, i.e. they contribute to the rigidity of the plant body.

2. **Cutinization.** This is the transformation of cellulose or some of the pectoses into a substance known as cutin. Cutin is waxy in nature. It forms a definite layer, called the cuticle, on the skin of the stem and the leaf. It makes the cell-wall impermeable or very slightly permeable to water. Its function is to prevent or check evaporation of water from the exposed surfaces of the plant.

3. **Suberization.** The cell-wall is often charged with a substance called suberin. Suberization occurs in the walls of cork cells. The cells of the bottle cork are suberized. Suberin is a fatty substance and makes the cell-wall impervious to water and, therefore, like cutin, it also prevents or checks evaporation of water.

4. **Mucilaginous Change.** Cellulose may also undergo change into a sort of slimy substance known as mucilage. It absorbs water greedily, retains it tenaciously and forms a viscous mass; but when dry, it is very hard and horny. It is insoluble in alcohol. Mucilage is copious in the fleshy leaves of Indian aloe (B. GHRITAKUMARI; H. GHIKAVAR). It is also abundant in the flowers of China rose, in the fruits of lady's finger, in the branches and leaves of Indian spinach (*Basella*; B. PUIN; H. POI), and in the seeds of linseed, *Plantago* (B. ISOBGUL; H. ISOBGOL), *Lallemantia* (B. & H. TOPMARI), etc. Such seeds, when wetted, swell up and become mucilaginous. Mucilage also occurs in the fleshy leaves of desert plants.

Mineralization. Various mineral crystals (see FIGS. 16-18) may be introduced into the cell-wall. Of these, silica or sand particles and calcium oxalate crystals are fairly common. Silica occurs most commonly in the leaves of grasses. Calcium oxalate crystals are widely [illegible]

[illegible]

In the majority of fungi, and sometimes also in algae, the [illegible] walls are made up of *chitin*—a substance allied to cellulose. Chitin, however, is peculiar to animals.

Micro-chemical Tests of the Cell-wall

Reagents	Cellulose	Lignin	Cutin and Suberin	Mucilage
1 Iodine solution	pale yellow	deep yellow	deep yellow	—
2 Chlor-zinc-iodine	blue or violet	yellow	yellowish brown	—
3 Iodine solution + sulphuric acid or zinc chloride	blue	brownish	deep brown	violet
4 Aniline sulphate (acid)	—	bright yellow	—	—
5 Phloroglucin (acid)	—	violet red	—	—

6 Caustic potash solution (concentrated)	—	—	yellow and brown	—
7 Potash+chlor-zinc-iodine	—	—	violet	—
8 Chlorophyll solution	—	—	green	—
9 Sudan IV	—	—	red	—
10 Methylene blue	—	—	—	deep blue

Cell Inclusions (non-living)

Various substances appear in the plant body as products of metabolism or as by-products. These are called **ergastic substances** and may be (A) reserve materials, (B) secretory products, and (C) waste products. They may occur in the vacuole (particularly the soluble ones) or in the cytoplasm (particularly the insoluble ones) or even in the cell-wall (particularly some of the waste products).

A. **Reserve Materials.** These are substances manufactured by the protoplasm and stored up by it in particular cells. The various materials thus stored up are ultimately utilized by the protoplasm for its own nutrition as well as for the construction of the plant body. Thus the reserve materials are the *food* of plants. Many of the materials exist in solution in the cell-sap; others are deposited in solid form. The reserve materials include the various kinds of (1) **carbohydrates,** (2) **nitrogenous materials,** and (3) **fats and oils.**

1. **Carbohydrates.** These are substances containing carbon, hydrogen and oxygen. Of these, hydrogen and oxygen occur in the same proportion as they do in water. The general chemical formula is $C_x(H_2O)_y$. When these substances are heated they become charred, forming a black mass. This black mass is carbon. The water escapes and the carbon is left behind. From the economic standpoint carbohydrates are very important. Many of them are extensively consumed as food, many are largely employed in various industries as in the manufacture of fabrics and paper, and many are used for production of alcohol.

(1) **Sugars.** Sugars are sweet, crystalline, white and soluble substances and are of various kinds such as grape-sugar or glucose (a reducing sugar) chiefly found in grapes; fruit-sugar or fructose (a reducing sugar) found in many fruits associated with glucose; it may be readily formed from glucose or by hydrolysis of sucrose; cane-sugar or sucrose (a non-reducing sugar) chiefly found in sugarcanes and beet-roots; and malt-sugar or maltose (a reducing sugar) formed by the action of diastase (an enzyme) on starch and, therefore, commonly present in germinating seeds, particularly cereals. Grape-sugar is the simplest of all carbohydrates and is formed in the leaves by chloroplasts *in the presence of sunlight*. Other forms of carbohydrates are derived from it with or without the help of the living substance.

Glucose travels in the plant body as such until it reaches the storage tissues, where it is mostly converted into starch, an insoluble carbohydrate, and deposited for a shorter or a longer period. This starch may again be converted into sugar. The chemical formula of grape-sugar is $C_6H_{12}O_6$, and that of cane-sugar $C_{12}H_{22}O_{11}$. Glucose contents of grapes are 12-15% or more, of apples 7-10%, and of plums 3-5%; sucrose contents of sugarcanes 10-15%, and of beet-roots 10-20%.

Test for Glucose. Add Fehling's solution or an alkaline solution of copper sulphate to it, boil, and a yellowish red precipitate of *cuprous oxide* is formed. **Test for Sucrose.** Boil sucrose solution with 1 or 2 drops of *sulphuric acid*, and then apply the test for glucose.

Classification of Carbohydrates. (*a*) Monosaccharides (sugars) are the simplest ... [illegible]

[illegible] densation products of simple sugars, e.g. inulin, starch, *dextrin* and glycogen (cellulose and hemicellulose also belong to this group). (*d*) *Compound* carbohydrates (non-sugars) are complex carbohydrates *formed* by combination of carbohydrate-molecules with non-carbohydrate-molecules, e g. *gums*, *mucilages*, tannins and glycosides.

place in the germinating seeds under the action of hydrolytic enzymes such as diastase and maltase.

(2) **Inulin** (FIG. 12). Inulin is a soluble carbohydrate, and occurs in solution in the cell-sap. Like starch it is easily converted into a form of sugar. Inulin is present in the tuberous roots of *Dahlia* and some other plants of *Compositae*. When pieces of *Dahlia* roots are steeped in alcohol or glycerine for 6 or

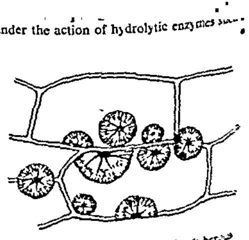


FIG. 12. Inulin crystals in the tuberous root of *Dahlia*.

7 days, preferably more, inulin becomes precipitated in the form of spherical crystalline masses. A section is then prepared from one of the pieces and examined under the microscope. Inulin may also be precipitated by cutting rather thick sections from fresh material and keeping them in strong alcohol for about an hour. Under the microscope fully-formed inulin crystals are seen to be star- or wheel-shaped, and half-formed ones more or less fan-shaped. These crystals are deposited mostly across the cell-walls, and occasionally only in the cell-cavity. Sometimes these crystals are so large that they extend through many cells. Inulin has the same chemical composition as starch, viz. $(C_6H_{10}O_5)n$. When precipitated, inulin is easily recognized by its peculiar form.

(3) Starch (FIGS. 13-14). This is an insoluble carbohydrate occurring as a reserve food in the form of minute grains. Starch grains are of

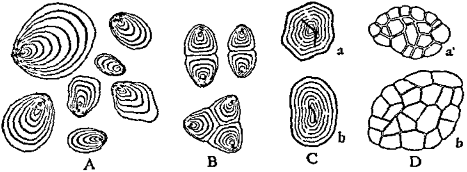


FIG. 13. Starch Grains. *A*, simple eccentric grains in potato; *B*, compound grains in the same; *C*, *a*, simple concentric grain in maize; *b*, ditto in pea; *D*, *a*, compound grain in rice; *b*, ditto in oat.

universal occurrence in plants with the exception of fungi. They occur in almost all parts of plants, but in storage tissues they are specially

rod- or *dumb-bell-shaped*, as in the latex cells (see FIG. 37A). They also vary very much in size, the largest known being about 100 microns (μ) in length, as in the rhizome of *Canna*, and the smallest about 5 microns (μ) in length, as in rice. In potato they are of varying sizes. Starch may be synthesized in the green cells by the chloroplasts, called *assimilation starch*, or in the non-green cells by the leucoplasts (amyloplasts), called *storage starch*. In any case it is formed from glucose under the action of an enzyme (phos-

practically absent from mature, inactive tissue. A common form of insoluble or sparingly soluble protein abundantly found in the endosperm of the castor seed is the aleurone grain (FIG. 15). Each aleurone grain is a solid, ovate or rounded body, and encloses in it a crystal-like body, known as the crystalloid, and a rounded mineral body, called the globoid. The crystalloid occupies the wider part of the

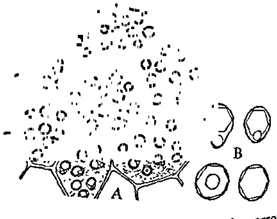


FIG. 15. Aleurone grains. *A*, grains in the endosperm cells of castor seed; *B*, a few grains (magnified). Note the crystalloid and the globoid.

grain and is protein in nature, while the globoid occupies the narrower part and is a double phosphate of calcium and magnesium. The occurrence of crystalloid and globoid is not always constant in the aleurone grain. There may be one or more of them, or sometimes none at all. Aleurone grains vary in size. When they occur with starch they are very small, as in pea; but in oily seeds they are very much larger, as in castor.

Fatty seeds usually contain a higher percentage of proteins than starchy seeds, e.g rice contains only 7% of proteins, wheat 12%, while sunflower seeds contain proteins as high as 30%. Starchy seeds of leguminous plants, however, contain as high a percentage of proteins as fatty seeds, e.g. in the pulses there is an average of about 25% of proteins; in soybean (*Glycine max*) protein contents vary from 42-47%.

Tests for Proteins. (1) Proteins are coloured yellowish brown with strong iodine solution (see No. 5). (2) Xanthoproteic reaction—by adding some strong nitric acid a white precipitate is formed; on boiling it turns yellow. After cooling add a little strong ammonia and the yellow colour changes to orange. (3) Millon's reaction—add Millon's reagent (nitrate of mercury) and a white precipitate is formed; on boiling it turns brick-red. (4) Biuret reaction—an excess of caustic soda followed by a few drops of copper sulphate gives a violet colour which deepens on heating. (5) Treat a thin section of castor endosperm with 90% alcohol for 3-4 minutes and then with strong iodine solution. Mount it in thick glycerine and note under the microscope that the aleurone grains and the crystalloids turn deep brown, while the globoids remain colourless. Add 1% or 2% caustic soda solution to a fresh section and note that the aleurone grains get dissolved, while the globoids remain unaffected. Treat another section with dilute acetic acid and see that only the globoids get dissolved.

Hydrolysis of Proteins. When proteins are subjected to hydrolysis, i.e. when treated with a mineral acid or acted on by enzymes such as trypsin, they are finally resolved into amino-acids out of which they have been built up, after passing through intermediate stages, as follows proteins → metaproteins → proteoses → peptones → polypeptides → amino-acids

(2) **Amino-compounds.** Amino-acids and amines are the simplest forms of all nitrogenous food materials, and occur in solution in the cell-sap. They are abundantly found in the growing regions of plants, less frequently in storage tissues. When translocation is necessary, proteins become converted into amines and amino-acids. The amines and amino-acids travel to the growing regions where the protoplasm is very active, and they are directly assimilated by it. They are also the initial stages in the formation of complex proteins. They contain carbon, hydrogen, oxygen and nitrogen, and in the amino-acid, cystine, sulphur is also present. Some of the principal amino-acids are cystine, alamine, tyrosine, glycine, leucine, aspartic acid, glutamic acid, etc.

3. **Fats and Oils.** Fats and oils occur to a greater or less extent in all plants. They occur in the form of minute globules in the protoplasm of the living cells where they are formed, and cannot travel from cell to cell. In the 'flowering' plants often special deposits of them are found in seeds and fruits. But in starchy seeds and fruits there is very little fat. Fats and oils are composed of carbon, hydrogen and oxygen, but the last two do not occur in the same proportion as they do in water—the proportion of oxygen being always much less than in the carbohydrates. They contain no nitrogen. They are insoluble in water, but very readily soluble in ether, petroleum and chloroform. Comparatively few of them are soluble in alcohol, e.g. castor oil. Fats are synthesized in living bodies from fatty acids

amount of *energy* stored in them. Their energy value is more than double that of the carbohydrates. When fats are decomposed the energy stored in them is liberated and made use of by the protoplasm for its manifold activities. Digestion of fats into fatty acids and glycerine is also brought about by the enzyme *lipase*. Fats that are liquid at ordinary temperature are known as 'oils'. In plants fats are usually present in the form of oils. Oils are of two kinds, viz. *fixed* or *non-volatile*, as described above, and *essential* or *volatile* (see pp. 154-5).

A large number of them are used for food, for manufacture of soap and oil-paints, for illumination, lubrication, etc., and are, therefore, of considerable economic importance, e.g. coconut oil, olive oil,

sesame or gingelly oil, castor oil, groundnut oil, linseed oil, mustard oil, cotton seed oil, etc.

Tests for Fats and Oils. (1) Osmic acid (1% aqueous solution) stains them black (2) Alcoholic solution of Sudan III, Sudan IV, or Sudan Red stains them red. (3) Alcoholic solution of alkanet (or alkannin) stains them red, but the stain develops only after an hour or so. (4) Pressed against a paper they leave a permanent greasy mark on it.

B. [illegible] digestion of food; chlorophyll helps in the manufacture of carbohydrates; anthocyanin is responsible for many colours of flowers; and nectar secreted by many flowers serves to attract insects for pollination.

C. [illegible] They may be (I) non-nitrogenous or (II) nitrogenous.

I. NON-NITROGENOUS

1. Tannins. [illegible] widely distr[illegible] cell-sap, either in single isolated cells or in small groups of cells in almost all parts of the plant body. They are also found in the cell-walls, often abundantly in certain dead tissues, as in the bark and the heart-wood. In the leaves, young and old, and in many unripe fruits tannins are abundant. As the fruits ripen tannins disappear; they become converted into glucose and other substances. They are abundant in the fruits of myrobalans, e.g. chebulic myrobalan (B. HARITAKI; H. HARARA), beleric myrobalan (B. BAHERA; H. BHAIRAH), emblic myrobalan (B. AMLA; H. AMLIKA). Tea leaves contain about 18% of tannin. Catechu, a kind of tannin, is obtained from the heart-wood of *Acacia catechu*, and is also present in betel- or arecanut. Tannin is a bitter substance, and that is why 'very strong' tea and fruits of myrobalans taste bitter. It is aseptic, i.e. free from the attack of parasitic fungi and insects. The presence of tannin makes the wood hard and durable. Tannins have a variety of uses. Mixed with iron salts they are used in the manufacture of ink. They are extensively used in tanning, i.e. converting hide into leather. They are also used for various medicinal purposes. They turn blue-black with an iron salt such as ferric chloride.

2. Essential Oils. These are volatile oils, and occur mostly in glands,

known as *oil-glands* (see FIG. 38A). The transparent spots in the leaves of sacred basil, pummelo or shaddock, lemon, lemon grass (*Cymbopogon*), *Eucalyptus*, etc., and those in the rind of fruits like orange, lemon, shaddock, etc., are all oil-glands. They are also present in the petals of flowers of many plants, as in rose, jasmines, etc. The fragrant odour of such flowers is due to the presence of essential oils contained in them. They differ from fatty oils in their chemical composition as well as in being volatile. They are sufficiently soluble in water to impart to it their taste and odour. Being volatile, essential oils are obtained from plants by distillation, whereas fixed oils may [illegible] readily [illegible] 154). [illegible] some [illegible] es are lemon oil, eucalyptus oil, clove oil, lavender oil, sandalwood oil, thyme oil, etc.

3. **Resins.** These are mostly found in the stems of conifers, and occur in abundance in special canals or ducts, known as *resin-ducts* (see FIG. 26). They are yellowish solids, insoluble in water but soluble in alcohol, turpentine and spirit. When present in the wood, resins add to its strength and durability. They occur associated with a small quantity of turpentine which is removed by distillation, and the residue is pure resin.

4. [illegible]

5. **Mineral Crystals.** The common forms of crystals consist of silica, calcium carbonate and calcium oxalate. They occur either in the cell-cavity or in the cell-wall. Of them, crystals of calcium oxalate are most common, and are very widely distributed among various plants.

(1) Silica occurs as an incrustation on the cell-wall or it lies embedded in it. It is most frequently found in the leaves of

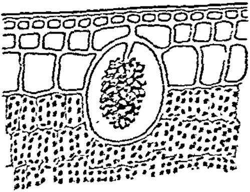
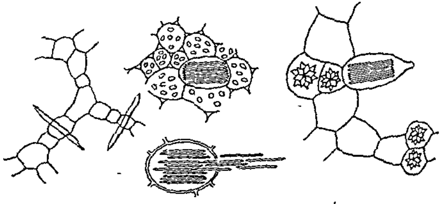


FIG. 16. Mineral Crystals. Cy[illegible] the leaf of India-rubber [illegible]

grasses and in *Equisetum*. Wheat straw contains about 72% of silica, rye straw about 50% and *Equisetum* about 71%.

(2) **Calcium carbonate** occurs in the form of a crystalline mass, often pear-shaped in appearance, in the leaf of *Ficus* (e.g. India-

a bunch of grapes suspended from a stalk. When cystolith is dissolved, the cellulose matrix on which crystals are deposited shows stratifications and radial striations. Cystolith is also found in the leaf and stem of many plants of *Acanthaceae*.



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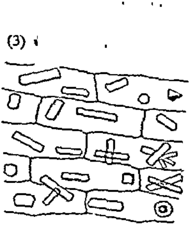


FIG. 18. Mineral Crystals (*contd.*). Various forms of calcium oxalate crystals in the dry onion scale.

crystals, and (*c*) octahedral and other forms. (*a*) **Raphides** (FIG. 17) are needle-like crystals occurring singly or in bundles. These are found in most of the plants in smaller or larger quantities, but are specially common in water hyacinth, water lettuce, balsam and aroids such as taro (*Colocasia*), *Alocasia*, *Amorphophallus*, etc. They are frequently shut off by a cell-wall from coming in contact with the protoplasm. (*b*) Conglomerate crystals or

sphaero-crystals (FIG. 17C) are clusters of crystals which radiate from a common centre, and hence have a more or less star-shaped appearance. They are found in water lettuce (*Pistia*), taro (*Colocasia*), etc. (*c*) **Octahedral, cubical, prismatic and rod-like crystals** (FIG. 18) of calcium oxalate are also common in plants; they can be readily seen in the dry scales of onion.

Tests. (*a*) 50% nitric acid solution (or any other mineral acid) dissolves both calcium carbonate and oxalate crystals, but bubbles of CO_2 gas are evolved only in the case of carbonate crystals. (*b*) 30% acetic acid solution readily dissolves calcium carbonate crystals only, but not the oxalate crystals.

6. **Latex.** This is a milky juice found in latex cells and latex vessels (see FIG. 37). Latex occurs as an emulsion consisting of a variety of [illegible] some poisonous substances. The function of latex is not clear; perhaps in some way it is associated with nutrition, healing of wounds and protection against parasites and animals. Latex of *Hevea* is the source of rubber. Latex is sometimes coloured (yellow, orange or red), as in opium poppy, garden poppy, prickly poppy, etc.

7. **Organic Acids.** Living cells give an acid reaction. This is due to the presence of organic acids in the cell-sap. There are various kinds of such acids in plants, e.g. tartaric acid in tamarind, pineapple and grape; citric acid in *Citrus* (e.g. lemon, orange and shaddock or pummelo); oxalic acid in wood-sorrel (*Oxalis*) and sorrel (*Rumex*); and malic acid in the leaves of gram and *Bryophyllum* and also in many unripe fruits. The sour taste of many fruits, particularly of unripe ones, is due to the presence of some such acids in them.

II. NITROGENOUS

Alkaloids. These are complex nitrogenous substances, and occur combined with some organic acids, mostly in seeds and roots of some plants. They have an intensely bitter taste and many of them are extremely poisonous. A few of them are liquids; majority of them are, however, crystalline solids which are insoluble or sparingly soluble in water, but readily so in alcohol. There are over 200 known alkaloids found in plants, of which a few may be mentioned here. These [illegible] in *Datura*, solanine in bitter-sweet (*Solanum dulcamara*; B. MITHA-BISH), and so on.

stem-tip. The changes comprise four stages: *prophase*, *metaphase*, *anaphase and telophase*.

Prophase. The metabolic nucleus contains in its karyolymph numerous crooked, often coiled, delicate threads called **chromonemata**, not recognizable as distinct entities. The first sign of the prophase is the appearance of a certain number of distinct, slender threads called **chromosomes** (B). The chromosomes, particularly the longer ones, are more or less spirally coiled. Close scrutiny shows that the individual chromosomes are always longitudinally double, with the two threads remaining closely coiled about each other throughout their length, and each longitudinal half of the chromosome is called a **chromatid**. Chromosomes are composed of nucleoproteins, and are the vehicles of genes or hereditary factors. As prophase proceeds the chromosomes relax their coils and thicken somewhat (C). Their double nature becomes more apparent. The outlines of the chromatids present a slightly irregular, hairy appearance. Soon, however, they lose their hairiness and become thicker and smoother. It is also seen that each chromatid divides longitudinally into two. Thus a chromosome at this stage consists of four threads (chromonemata), two belonging to a chromatid. Further, a chromosomal substance accumulates in a sheath or matrix round each chromatid and the two threads become closely coiled in it (D). In well-fixed chromosomes some unstained gaps or constrictions are seen; these are the attachment regions, called centromeres. The matrix soon becomes more apparent, and the nucleoli lose their staining power and disappear completely. The nucleus then rapidly

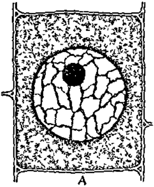


FIG. 19*A*. Mitosis. Metabolic nucleus.

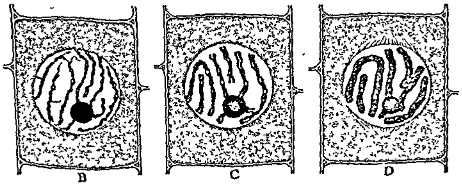


FIG. 19. *B-D*. Mitosis (*contd*.). Prophase.

Fig. 19 A–J redrawn after Fig. 40 in Fundamentals of Cytology *by L. W. Sharp by permission of McGraw Hill Book Company. Copyright 1943.*

Contents of the Vacuole. The vacuolar sap may contain as much as 98% of water, and dissolved in it some of the reserve materials, secretory products and waste products. Although the cell-sap is specially rich in soluble substances, it often contains some solid bodies in amorphous or crystalline condition. (1) In-

[illegible]

are specially common in the cell-sap, e.g. grape-sugar in grapes, cane-sugar in sugarcane, inulin in *Dahlia*, etc. (4) Of the nitrogenous materials *soluble proteins*, amines and amino-acids occur dissolved in the cell-sap, particularly in the cells of the growing regions and to some extent only in the storage cells. (5) Of the secretory pro[illegible] frequently occur in the petals of flowers and also in the yo[illegible] the cell-sap. [illegible] of the waste products are also common in particular cells. These are tannins, [illegible] alkaloids and glucosides. Glucosides [illegible] rise to a kind of sugar together with [illegible] Common glucosides are saponin of [illegible] dalin of bitter almond, etc. Their use as reserve materials is [illegible] cases because of the sugar they contain. In many cases, however, glucosides are distinctly poisonous.

Formation of New Cells

Plants, however big and complicated their body may ultimately be, begin their existence as a single cell—the embryonic or egg-cell. But they have to grow from the initial stage to their normal size and form. Growth in them is initiated by the formation of new cells and their enlargement, and two processes are closely associated in this direction: first, division of the nucleus (mitosis) and second, division of the cell (cytokinesis). The division of the egg-cell begins often immediately after fertilization and continues, sometimes after a resting period, throughout the life of a plant, but later with the formation of the tissues and organs cell-formation becomes mostly restricted to the [illegible]

plant body or in different plants. The methods are as follows.

1. **Somatic Cell Division.** Cell division leading to the development of the vegetative body (soma) of the plant is known as somatic cell division. It includes the division of the nucleus, called *mitosis* (*mitos*, thread) or *karyokinesis* (*karyon*, nut or nucleus) or *indirect nuclear division*, and the division of the cytoplasm, called cytokinesis.

Mitosis (FIG. 19). In this process the metabolic nucleus (A) passes through a complicated system of changes, most essentially the longitudinal doubling of chromosomes and the even distribution of longitudinal halves among the two daughter nuclei, which can be studied in properly fixed and stained preparations of the root-tip or the

stem-tip. The changes comprise four stages: *prophase*, *metaphase*, *anaphase and telophase*.

Prophase. The metabolic nucleus contains in its karyolymph numerous crooked, often coiled, delicate threads called **chromonemata**, not recognizable as distinct entities. The first sign of the prophase is the appearance of a certain number of distinct, slender threads called **chromosomes** (B). The chromosomes, particularly the longer ones, are more or less spirally coiled. Close scrutiny shows that the individual chromosomes are always longitudinally double, with the two threads remaining closely coiled about each other throughout their length, and each longitudinal half of the chromosome is called a **chromatid**. Chromosomes are composed of nucleoproteins, and are the vehicles of genes or hereditary factors. As prophase proceeds the chromosomes relax their coils and thicken somewhat (C). Their double nature becomes more apparent. The outlines of the chromatids present a slightly irregular, hairy appearance. Soon, however, they lose their hairiness and become thicker and smoother. It is also seen that each chromatid divides longitu-

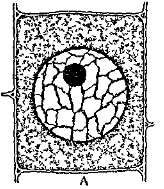


FIG. 19*A*. Mitosis. Metabolic nucleus.

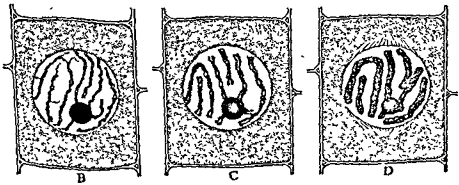


FIG. 19. *B-D*. Mitosis (*contd.*). Prophase.

dinally into two. Thus a chromosome at this stage consists of four [illegible] Further, a [illegible]rix round [illegible] in it (D). In well-fixed chromosomes some unstained gaps or constrictions are seen; these are the attachment regions, called centromeres. The matrix soon becomes more apparent, and the nucleoli lose their staining power and disappear completely. The nucleus then rapidly

Fig. 19 A-J redrawn after Fig. 40 in Fundamentals of Cytology *by L. W. Sharp by permission of McGraw Hill Book Company. Copyright 1943.*

passes into the next stage, the metaphase, through a complicated series of changes.

Metaphase. The nuclear membrane disappears and a spindle-like body known as the **nuclear spindle** (usually bipolar, in some cases multipolar or even monopolar) is formed (E). The mode of origin of the spindle varies considerably. It may be formed entirely out of the nuclear sap (or karyolymph), or, it may appear, commonly in root-

the chromatids come even more closely together. From the centromeres of each pair of chromatids fibre-like extensions, called *tractile fibres*, are formed towards the opposite poles through the nuclear spindle. The number of chromosomes is normally constant for a particular species of plants and this number is also normally even, expressed as $2n$ (or $2x$) or diploid. Chromosome numbers cover a wide range but 24 seems to be a common figure.

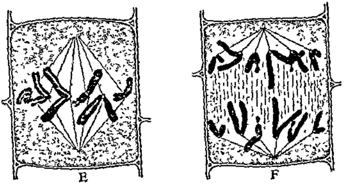


FIG. 19. E-F. Mitosis (contd.). E, metaphase; F, anaphase.

Anaphase. At the end of the metaphase the centromeres of each pair of chromatids appear to repel each other. They diverge and move ahead towards the two opposite poles along the course of tractile fibres (F). The movement of the chromatids is autonomous. The causes of this movement are, however, not clearly understood. The chromatids soon become separated from each other. The spindle may also undergo elongation and thus help the complete separation

opposite poles of the spindle.

Telophase. At each pole the chromatids (now regarded as chromosomes) form a close group (G). The polar caps of the spindle disappear and a nuclear membrane is formed round each group of chromosomes (H). Nucleoli reappear at definite points on certain chromosomes. The spindle body disappears and so does the matrix.

The chromosomes reorganize as two nuclei. The nuclear sap reappears and each nucleus increases in size (I). It passes into the meta-

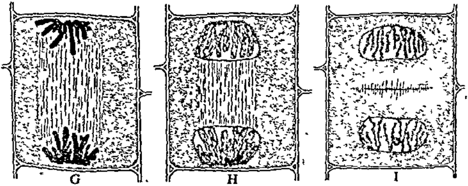


FIG. 19. *G-I.* Mitosis (*contd.*). Telophase.

bolic stage or prepares for the next division. The duration of mitosis varies considerably in different plants and also in the same plant under different conditions. In this respect temperature is an impor-

135 minutes at 10°C.

Cytokinesis or *the division of the cytoplasm and the formation of the cell-wall.* Cytokinesis has recently been the subject of considerable investigation. The division of cytoplasm appears to take place in one of two ways: by the formation of a new cell-wall in the equatorial region or by furrowing (i.e. by cleavage of the cytoplasm). The former process, known as the cell-plate method, is the usual one in vegetative division. It usually begins in the telophase when new cellulose particles are gradually deposited in the equatorial zone, and soon these particles fuse together to form a delicate membrane, dividing the cytoplasm into two new cells (J). In the latter process, as in the formation of pollen grains in the anther (see FIG. I/114J) constrictions or furrows appear in the ectoplast and these gradually proceed within, dividing the cytoplasm into two parts.

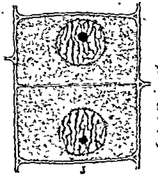


FIG. 19. *J.* Mitosis (*contd.*). Cytokinesis.

and quantitatively similar to the mother nucleus. Chromosomes are the bearers of hereditary characters and because of even distribution of chromosomal substance the two daughter nuclei possess all the characteristics and qualities of the mother nucleus.

Structure of the Chromosome (FIG. 20). The structure of the chromosome may best be studied in its metaphase or anaphase stage, preferably in the latter. It must be noted that the chromosomes always appear in their characteristic shapes and sizes, apart from their constant number, in the succeeding divisions of the nucleus so far as a particular species of plants is concerned. Most commonly the anaphasic chromosomes of somatic cells lie within limits of 1-20μ in length. Long chromosomes of course give a better idea of their constitution. As previously stated, a chromosome consists of two parts: usually two spiral threads, called *chromonemata*, twisted about each other, and a chromosomal matrix, often very clear at certain stages of *mitosis*. The two chromonemata are sometimes so closely associated that their double nature cannot be clearly made out. This has led to a controversy as to their true nature—single or double, or more according to some. The evidence is, however, in favour of *two* chromonemata. Along the whole length of each chromonema there is a series of granules, called *chromomeres*, which look like beads in a chain. These are, however, more clear in meiosis rather than in mitosis. The attachment region or centromere (also called kinetochore or primary constriction) is a very important part of the chromosome. Tractile fibre extends from it to the pole. The position of centromere is always constant in a given chromosome, as seen in successive divisions. It is a clear achromatic zone. The chromonemata are continuous through this zone, and each of them may contain a minute granule or ... called kinosome). The ... portions ... on ... centromere ... or unequal ... of ... mere. ... of a nucleus ... arms, ... both, a ... with the

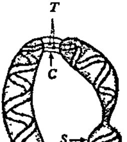


FIG. 20. Structure of a chromosome at anaphase stage. *T*, tractile fibres; *C*, centromere; *S*, satellite; *CH*, chromonema; *M*, matrix. *Redrawn after Fig. 57 in* Fundamentals of Cytology *by L. W. Sharp by permission of McGraw-Hill Book* ... *Copyright* ...

covered by Strasburger in 1888, is a complicated process of nuclear division whereby the chromosome number is reduced to half (n) in the four nuclei so formed by this method. Supposing then that the mother nucleus bears 12 chromosomes ($2n$), each of the daughter nuclei will have only 6. Reduction division takes place in all sexually reproducing organisms at some time in their life-cycle. Sexual reproduction means the fusion of a male gamete with a female one resulting in the formation of a zygote from which the offspring develops in due course. Had the gametes contained the same number of chromosomes as their parents the offspring would have an increasing number of chromosomes from generation to generation apart from the peculiar composition of the latter. In consequence the offspring would have developed into new, peculiar and distinct types since chromosomes are the bearers of hereditary characters and meiosis is the mechanism for the transmission of these characters. Thus in all sexually reproducing plants and animals the gametes are haploid (n) to compensate for the chromosome doubling ($n+n=2n$) in the zygote as a result of fertilization. In higher plants showing an alternation of generations meiosis occurs as soon as a plant enters into the gametophytic phase in its life-cycle and, therefore, during the formation of spores from the spore mother cell. In lower plants on the other hand meiosis occurs immediately after fertilization or on the germination of the zygote.

Process. Meiosis comprises two successive divisions of the mother nucleus (meiocyte) of which *division I* is the reduction division whereby the chromosome number is reduced to half (n), and *division II* is mitotic in nature. This being so, the four nuclei that are formed have the same reduced number (n) of chromosomes. Division I (FIG. 21A). In this division also the nucleus passes through the same phases, as in mitosis, but there are certain special features of meiosis during the prophase which being a prolonged one has been subdivided into the following stages. *Leptotene* (A). At the early prophase the chromosomes appear as long and slender threads (each thread is a single chromatid and not double, as in mitosis). These threads which are evenly distributed within the nucleus are seen to be present in identical pairs, i.e. for each thread there is a corresponding one similar to it in all respects, one being paternal and the other maternal. In each thread there is a definite number of granules known as chromomeres which appear like beads of various sizes. Leptotene actually represents the first appearance of chromosomes in the form of single slender threads in the diploid number. *Zygo-* [illegible] condition. Immediately after pairing the chromosomes begin to shorten and thicken. *Pachytene* (C). The paired chromosomes at this stage are distinctly shorter and thicker, and they are present in haploid number. They split longitudinally, and four chromatids (two from each homologue) are produced.

tene (D). At this stage a sort of repulsive force (or loss of attraction) develops between the homologous pairs of chromosomes and they begin to separate from each other. They remain, however, connected at one point (usually in shorter ones) or more points (usually in longer ones); these points are known as chiasmata. At each chiasma the chromosomes exchange 'genes' by *crossing over* (see FIG. VIII/2) This crossing over is a special feature of meiosis. The chromosomes

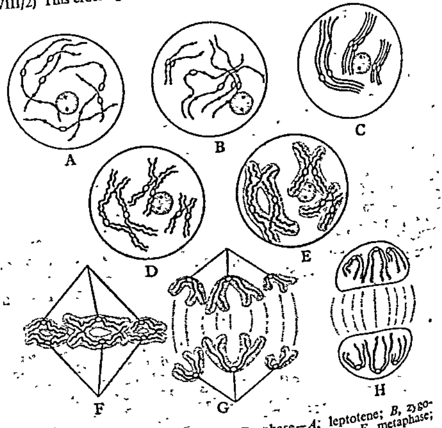


FIG. 21*A*. Meiosis. Division I: Prophase—*A*, leptotene; *B*, zygotene; *C*, pachytene; *D*, diplotene; *E*, diakinesis; *F*, metaphase; *G*, anaphase; *H*, telophase.

...horten and thicken at this stage and present a coiling appearance in a ... to the next stage. *Diakinesis* (E). At this ... assume their char... from one another ... Metaphase (F). The ... spindle makes its ...

within the nucleus, usually ... disappear. ... of the spindle. The four nuclear membrane and the nucleolus disappear ... by two ... appearance and the chromosomes collect at the c... (C chromatids (in two pairs) are now attached t... force, fairly apart from each other and facing opp... the tra... pairs now separate from each other, possi... towards the opposite poles of the spindle al... C...

Fig. 21*A* and Fig. 21*B* redrawn after Fig. ... -Graw-Hill ... L. W. Sharp by permission

Telophase (H). At the end of the anaphase the chromatid pairs (chromosomes) form a compact group at each pole. The two daughter nuclei, formed thus, contain haploid or (n) chromosomes, each with a pair of chromatids. Each nucleus then rests for a while or immediately passes on to division II (FIG. 21B) which is mitotic in nature. In the prophase (I) of this division the nucleolus reappears in each nucleus. The two chromatids of each chromosome, however, still remain separate and loose except at the chiasma. In the metaphase (J) the chromosomes

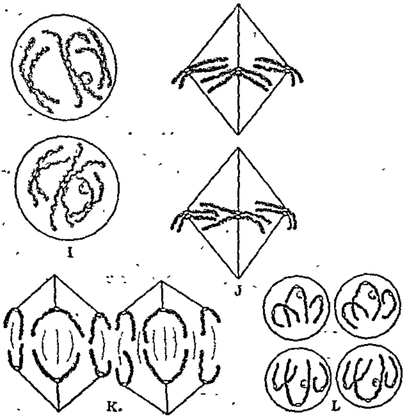


FIG. 21B. Meiosis (*contd.*). Division II. *I*, prophase; *J*, metaphase; *K*, anaphase; and *L*, telophase.

take up an equatorial position in the newly formed spindle, and the paired chromatids are separated. In the anaphase (K) the chromatids of each chromosom move apart towards the opposite poles of the spindle. In the telophase (L cytokinesis occurs and four nuclei are formed, each having one set of chromatids (now called chromosomes) reorganized in it.

Differences between Mitosis and Meiosis. (1) Mitosis occurs in somatic (meristematic) cells, while meiosis occurs in reproductive cells, resulting in the formation of spores or gametes. (2) In mitosis the chromosome number remains constant (diploid or $2n$), while in meiosis (or reduction division) the chromosome number is reduced to half (haploid or n). (3) In the prophase of both, the chromosomes appear in specific numbers but in mitosis they appear in double threads, while in meiosis they appear in single threads but in identical pairs. (4) Pairing (synapsis) of identical (homologous) chromosomes (one paternal and

tene (D). At this stage a sort of ... remain closely between the homologous pairs of ... but as they each other. They remain, howev... ones) or more points (usually in ... mata. At each chiasma the chromo... FIG. VIII/2). This crossing over is a

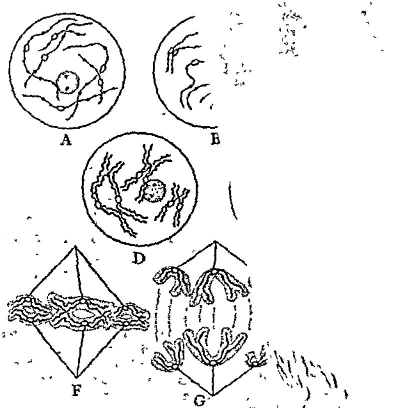


FIG. 21*A*. Meiosis. Division I: Prophase—... tene; *C*, pachytene; *D*, diplotene; *E*, diak... *G*, anaphase; *H*, telophase

further shorten and thicken at this stage and presen...

fairly apart from each other and facing ... pairs now separate from each other, ... repu... towards the opposite poles of the spin...

Fig. 21A and Fig. 21B redrawn after L. W. Sharp by permission of McGr...

Chapter 2 THE TISSUE

Cells grow and assume distinct shapes to perform definite functions. Cells of the same shape grow together and combine into a group for the discharge of a common function. Each group of such cells gives rise to a tissue. *A tissue is thus a group of cells or of vessels which are alike in form and function and have a common origin.* Tissues may primarily be classified into two groups: **meristematic** and **permanent**.

Meristematic Tissues (*meristos*, divided). These are composed of cells that are in a state of division or retain the power of dividing. These cells are either spherical, oval or polygonal in shape without any intercellular spaces; their walls thin and homogeneous; the protoplasm abundant and active with large nuclei; and the vacuoles small or absent. According to their origin meristems may be **primary** or **secondary**.

The **primary meristem** persists from the earliest stage of development of an organ of a plant, and according to its position may be **apical, lateral,** or **intercalary.** (*a*) The apical meristem lies at the apex of the stem and the root. (*b*) The intercalary meristem, when present, lies between masses of permanent tissues, either at the base of the leaf, as in pine, or at the base of the internode, as in some grasses, horsetail (*Equisetum*), etc., or sometimes below the node, as in mint; it is a detached portion of the apical meristem separated from the latter due to growth of the organ. The apical meristem, and also the intercalary meristem when present, give rise to *primary permanent* ... and are responsible for increase in length of the plant body. ...eral meristem, e.g. the cambium of the stem, lies along ... stem. It divides mainly in the radial direction, gives ... *permanent tissues* to the inside and outside of it and ...or

Intercellular Spaces. When the cells are young they remain closely packed without any empty space or cavity between them; but as they

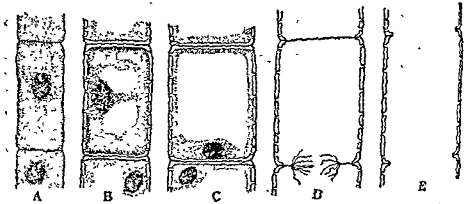


FIG. 25. Development of a vessel. *A-E* are stages in its development.

grow, their walls split at certain points, giving rise to small cavities or empty spaces; these are intercellular spaces. They remain filled with air or water.

Schizogenous Cavities. Bigger cavities are also often formed by the splitting up of common walls and the separation of masses of cells from one another; these are schizogenous (*schizein*, to split) cavities. Intercellular spaces and these cavities form an intercommunicating system so that gases and liquids can easily diffuse from one part of the plant body to the other. Most resin-ducts in plants are schizogenous cavities (FIG. 26).

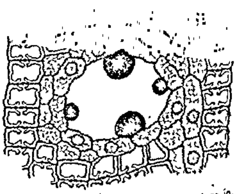


FIG. 26. Resin-duct of pine stem with resin.

Lysigenous Cavities. Sometimes, during the development of a mass of cells, their walls break down and dissolve, and as a consequence large irregular cavities appear; these are known as lysigenous (*lysis*, loosening) cavities. These cavities are meant for storing up water, gases, essential oils, etc., and thus act as glands (see FIG. 38A).

Chapter 2 THE TISSUE

Cells grow and assume distinct shapes to perform definite functions. Cells of the same shape grow together and combine into a group for the discharge of a common function. Each group of such cells gives rise to a tissue. *A tissue is thus a group of cells or of vessels which are alike in form and function and have a common origin.* Tissues may primarily be classified into two groups: meristematic and permanent.

Meristematic Tissues (*meristos*, divided). These are composed of cells that are in a state of division or retain the power of dividing. These cells are either spherical, oval or polygonal in shape without any intercellular spaces; their walls thin and homogeneous; the protoplasm abundant and active with large nuclei; and the vacuoles small or absent. According to their origin meristems may be primary or secondary.

The primary meristem persists from the earliest stage of development of an organ of a plant, and according to its position may be apical, lateral, or intercalary. (*a*) The apical meristem lies at the apex of the stem and the root. (*b*) The intercalary meristem, when present, lies between masses of permanent tissues, either at the base of the leaf, as in pine, or at the base of the internode, as in some grasses, horsetail (*Equisetum*), etc., or sometimes below the node, as in mint; it is a detached portion of the apical meristem separated from the latter due to growth of the organ: The apical meristem, and also the intercalary meristem when present, give rise to *primary permanent tissues*, and are responsible for increase in length of the plant body. (*c*) The lateral meristem, e.g. the cambium of the stem, lies along the side of the stem. It divides mainly in the radial direction, gives rise to *secondary permanent tissues* to the inside and outside of it and is responsible for growth in thickness of the plant body.

The secondary meristem, on the other hand, appears later at a certain stage of development of an organ of a plant. It is always lateral lying along the side of the stem and the root. It is seen that some of the primary permanent tissues become meristematic, i.e. they acquire the power of division, and constitute the secondary meristem, e.g. the cambium of the root, the interfascicular cambium of the stem and the cork-cambium. The secondary meristem is always lateral. All lateral meristems (primary and secondary) give rise to *secondary permanent tissues*, and are responsible for growth in thickness of the plant body.

Permanent Tissues. These are composed of cells that have lost the power of dividing, having attained their definite form and size. They may be living or dead and thin-walled or thick-walled. Permanent

tissues are formed by differentiation of the cells of the meristems and may be primary or secondary. The primary permanent tissues are derived from the apical meristems of growing regions and the secondary permanent tissues from the lateral meristems.

TISSUES

- Meristematic tissues
  - primary
    - apical → primary permanent tissues
    - intercalary → primary permanent tissues
    - lateral (e.g. cambium of stem) → secondary permanent tissues
  - secondary
    - lateral (e.g. cambium of root) → secondary permanent tissues
- Permanent tissues
  - primary permanent tissues
  - secondary permanent tissues

Note. The primary growth of the plant is due to enlargement of the cells of the primary permanent tissues which have been differentiated from the apical meristems (root-apex and stem-apex), and this is the same in both dicotyledons and monocotyledons. The secondary growth, on the other hand, is due to the formation of new (secondary) permanent tissues which have been cut off by lateral meristems such as the different cambial layers. In dicotyledons and gymnosperms the cambium is present, and by its activity the secondary growth takes place in these cases, while *in monocotyledons there is no cambium* and hence no secondary growth.

Classification of Permanent Tissues

In their earlier stages the cells are more or less similar in structure, but as the division of labour increases they gradually assume various forms and give rise to permanent tissues. These may be classified as *simple* and *complex*. A simple tissue is made up of one type of cells forming a homogeneous or uniform mass, and a complex tissue is made up of more than one type of cells working together as a unit. To these may be added another kind of tissue — the secretory tissue

called *chlorenchyma*; its function is to manufacture food material. A special type of parenchyma develops in many aquatic plants and in

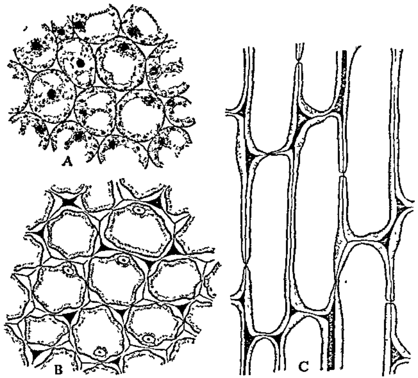


FIG. 27. *A*, parenchyma; *B*, collenchyma in transection; *C*, collenchyma in longitudinal section.

the petiole of *Canna* and banana. The wall of each such cell grows out in several places like rays radiating from a star and is, therefore, stellate or star-like in general appearance. These cells leave a lot of air cavities between them, where air is stored up. Such a tissue is often called *aerenchyma* (FIG. 28).

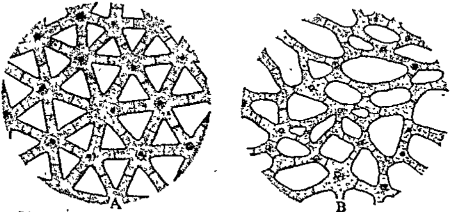


FIG. 28. *A*, aerenchyma in the petiole of banana; *B*, the same in the petiole of *Canna*.

2. Collenchyma (FIG. 27 B-C). This tissue consists of somewhat elongated parenchymatous cells with oblique, slightly rounded or tapering ends. The cells are much thickened at the corners against the intercellu[illegible]
secti[illegible]
preg[illegible]
fied. [illegible]
Collenchyma is found under the skin (epidermis) of herbaceous dicotyledons, e.g. sunflower, gourd, etc., occurring there in a few layers with special development at the ridge, as in gourd stem. It is absent from the root and the monocotyledon except in special cases. The cells are living and often contain a few chloroplasts. Being flexible in nature collenchyma gives tensile strength to the growing organs, and being extensible it readily adapts itself to rapid elongation of the stem. Containing chloroplasts it also manufactures sugar and starch. Its functions are, therefore, both mechanical and vital.

3. Sclerenchyma (FI[illegible]
very long, narrow, [illegible]

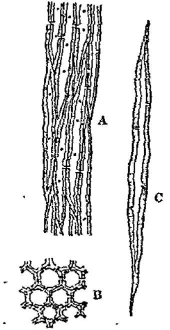


FIG. 29. Sclerenchyma; *A*, fibres as seen in longisection; *B*, the same as seen in transection; and *C*, a single fibre.

hence they are also called sclerenchymatous fibres, or simply **fibres**. Their walls often become so much thickened that the cell-cavity is nearly obliterated. They have simple, often oblique, pits in their walls. The middle lamella is conspicuous in sclerenchyma. Sclerenchymatous cells are abundantly found in plants, and occur in patches or definite layers which are seen to dovetail into each other in the longitudinal direction. Sometimes also they occur singly among other cells. They are dead cells, and serve a purely mechanical function, that is, they give strength and rigidity to the plant body and thus enable it to withstand various strains. Their average length is 1 to 3 mm. in angiosperms, and 2 to 8 mm. in gymnosperms. In special cases, as in hemp (*Cannabis*; B. & H. GANJA), rhea (*Boehmeria nivea*), flax (*Linum*), etc., the fibres are of excessive lengths ranging from 20 mm. to 550 mm. Such long, thick-walled cells make excellent textile fibres of commercial importance. Other common plants yielding long fibres are jute, coconut, Indian hemp (*Crotalaria juncea*; B. SHONE; H. SAN), Madras hemp

(*Hibiscus cannabinus*), sisal hemp (*Agave sisalana*), bowstring hemp (*Sansevieria*; B. MURGA; H. MARUL), rozelle (*Hibiscus sabdariffa*;

FIG. 30. Stone cells. *A*, as seen in transection; *B*, as seen in longisection.

and strongly lignified are not long and pointed, but are mostly isodiametric or irregular in shape or slightly elongated. They are dead and have a very narrow cell-cavity, and their walls are provided with many simple pits which are branched or unbranched. Stone cells may be somewhat loosely arranged or closely packed, and occur in hard seeds, nuts and stony fruits. They contribute to the firmness and hardness of the part concerned. Groups of stone cells may also be found among masses of parenchyma in the stem or the leaf or the fruit. The flesh of pear is gritty because of the presence of stone cells in it.

II. COMPLEX TISSUES

1. Xylem. Xylem or wood is a conducting tissue and is composed of elements of different kinds, viz. (*a*) tracheids, (*b*) vessels or tracheae (sing. trachea), (*c*) wood fibres and (*d*) wood parenchyma. Xylem as a whole is meant to conduct water and mineral salts upward from the root to the leaf, and to give mechanical strength to the plant body.

(*a*) Tracheids (FIGS. 31-3). These are elongated, tube-like cells with hard, thick and lignified walls and large cell-cavity. Their ends are tapering, either rounded or chisel-like, less frequently pointed. They are dead, empty cells with their walls provided with one or more rows of bordered pits. Tracheids may also be annular, spiral, scalariform or pitted (with simple pits). In transverse section they are mostly angular, either polygonal or rectangular. Tracheids (and not vessels) occur alone in the wood of ferns and gymnosperms, whereas in the wood of angiosperms they occur associated with the vessels. Their walls being lignified and hard, tracheids give strength to the plant body but their main function is conduction of water from the root to the leaf.

from which the transverse partition walls are absorbed (see p. 167). A vessel or trachea is thus a tube-like series of cells, very much like a series of water pipes forming a pipe line. Their walls are thickened in various ways, and according to the mode of thickening vessels

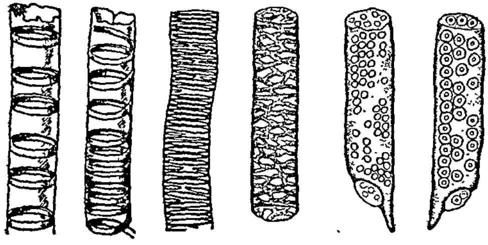


FIG. 34. Kinds of Vessels. *A*, annular; *B*, spiral; *C*, scalariform; *D*, reticulate; *E*, a vessel with simple pits; *F*, a vessel with bordered pits.

have received their names such as **annular, spiral, scalariform, reticulate,** and **pitted.** Associated with the vessels are often found some tracheids. Vessels and tracheids form the main tissues of the wood or xylem of the vascular bundle (see FIG. 47). They serve for conduction of water and mineral salts from the roots to the leaves. They are dead, thick-walled and lignified, and as such they also serve the mechanical function of strengthening the plant body

(*c*) **Wood Fibres.** Sclerenchymatous cells associated with wood or xylem are known as wood fibres. They occur abundantly in woody dicotyledons and add to the mechanical strength of xylem and of the plant body as a whole.

(*d*) **Wood Parenchyma.** Parenchymatous cells are of frequent occurrence in xylem, and are known as wood parenchyma. The cells are alive and generally thin-walled. The wood parenchyma assists, directly or indirectly, in the conduction of water upwards through the vessels and the tracheids; it also serves for food storage.

2. **Phloem.** Phloem or bast is another conducting tissue, and is composed of the following elements: (*a*) **sieve-tubes,** (*b*) **companion cells,** (*c*) **phloem parenchyma** and (*d*) **bast fibres** (rarely). Phloem as a whole meant to conduct prepared food materials from the leaf to the organs and the growing regions.

Sieve-tubes (FIGS. 35-6). Sieve-tubes are slender, tube-like structures and are composed of elongated cells, placed end on end. Their

(*b*) **Vessels or Tracheae** (FIG. 34). Vessels are cylindrical, tube-like structures; they are formed of a row of cells, placed end to end,

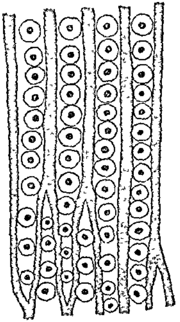


FIG. 31

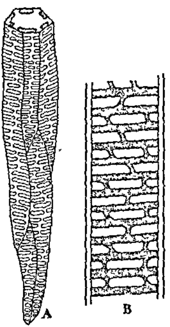


FIG. 32

FIG. 31. Tracheids of pine stem (in radial section) with bordered pits. FIG. 32. *A*, a scalariform tracheid of fern; *B*, a portion of the wall of the same magnified.

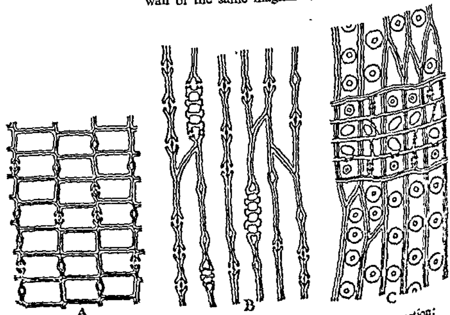
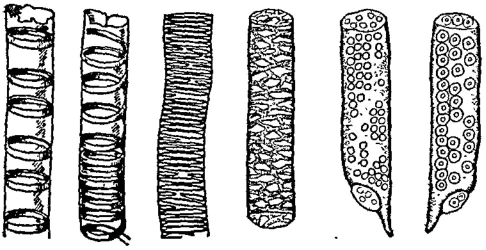


FIG. 33. Tracheids with bordered pits. *A*, pine stem in transection; *B*, the same in tangential (longitudinal) section; *C*, the same in radial (longitudinal) section.

from which the transverse partition walls are absorbed (see p. 167). A vessel or trachea is thus a tube-like series of cells, very much like a series of water pipes forming a pipe line. Their walls are thickened in various ways, and according to the mode of thickening vessels



A B C D E F

FIG. 34. Kinds of Vessels. *A*, annular; *B*, spiral; *C*, scalariform; *D*, reticulate; *E*, a vessel with simple pits; *F*, a vessel with bordered pits.

have received their names such as **annular, spiral, scalariform, reticulate,** and **pitted**. Associated with the vessels are often found some tracheids. Vessels and tracheids form the main tissues of the wood or xylem of the vascular bundle (see FIG. 47). They serve for conduction of water and mineral salts from the roots to the leaves. They are dead, thick-walled and lignified, and as such they also serve the mechanical function of strengthening the plant body

(*c*) **Wood Fibres.** Sclerenchymatous cells associated with wood or xylem are known as wood fibres. They occur abundantly in woody dicotyledons and add to the mechanical strength of xylem and of the plant body as a whole.

(*d*) **Wood Parenchyma.** Parenchymatous cells are of frequent oc- [illegible] ıyma. The cells [illegible] ·nchyma assists, [illegible] ɔwards through [illegible] storage.

2. **Phloem.** Phloem or bast is another conducting tissue, and is composed of the following elements: (*a*) sieve-tubes, (*b*) companion cells, (*c*) phloem parenchyma and (*d*) bast fibres (rarely). Phloem as a whole is meant to conduct prepared food materials from the leaf to the storage organs and the growing regions.

(*a*) **Sieve-tubes** (FIGS. 35-6). Sieve-tubes are slender, tube-like structures, and are composed of elongated cells, placed end on end. Their

walls are thin and made of cellulose; the transverse partition walls are, however, perforated by a number of pores. The transverse wall then looks very much like a sieve, and is called the sieve-plate. The sieve-plate may sometimes be formed in the side (longitudinal) wall. In some cases the sieve-plate is not transverse (horizontal), but inclined *obliquely*, and then different areas of it become perforated. A sieve-plate of this nature is called a *compound plate*. At the close of the growing season the sieve-plate is covered by a deposit of a colourless, shining substance in the form of a pad, called callus or callus pad. This consists of a carbohydrate, called *callose*. In winter the callus completely clogs the pores; but in spring, when the active season begins, it gets dissolved.

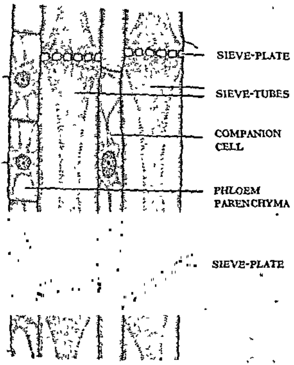


FIG. 35. Sieve tissue in longitudinal section.

In old sieve-tubes callus forms a permanent deposit. The sieve-tube contains no nucleus, but has a lining layer of cytoplasm which is continuous through the pores. Sieve-tubes are used for the longitudinal transmission of prepared food materials—proteins and carbohydrates—from the leaves to the storage organs and the growing regions of the plant body. A heavy deposit of food material is found on either side of the sieve-plate with a narrow median portion.

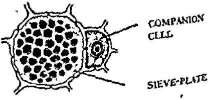


FIG. 36. Sieve-tube in transection.

(*b*) **Companion Cells.** Associated with each sieve-tube and connected with it by pores is a thin-walled, elongated cell, known as the companion cell. It is living, containing protopl[illegible] and an elong[illegible] nucleus. The companion cell is present [illegible] dicotyledons and monocotyledons). It [illegible]ve-tube [illegible] conduction of food.

(*c*) **Phloem Parenchyma.** There are al[illegible] [illegible]chym[illegible]

cells forming a part of the phloem in all dicotyledons, gymnosperms and ferns. The cells are living, and in shape often cylindrical. These store up food material and help in the conduction of the same. Phloem parenchyma is, however, absent in most monocotyledons

(*d*) **Bast Fibres.** Sclerenchymatous cells occurring in the phloem or bast are known as bast fibres. These are generally absent in the primary phloem but are of frequent occurrence in the secondary phloem.

Position of Phloem. Normally in angiospermic stems the phloem lies external to the xylem. But in many families of angiosperms such as *Solanaceae*, *Convolvulaceae*, *Apocynaceae*, *Myrtaceae*, *Compositae*, etc., a part of the *primary phloem*, called **intraxylary phloem**, better called **internal phloem**, is seen to occur, often in small groups or strands, internal to the primary xylem around the pith, either in association with this xylem or detached from it. The internal phloem is similar to the normal external phloem in origin, structure and composition but its ele- [illegible] bium forms here and there mostly on its inner side (rarely on the outer, as in *Strychnos*) amphivasal bundles (with phloem in the centre surrounded by xylem) which lie scattered in the ground tissue (see p. 194). Interxylary phloem is found in certain dicotyledons, e.g. nicker bean (*Entada*) and *Combretum* and among monocotyledons in some arborescent types showing secondary growth, e.g. *Dracaena* (see FIG. 75), *Yucca* (see FIG. I/78), *Agave*, *Aloe*, etc.

III. SECRETORY TISSUES

1. **Laticiferous Tissue.** This consists of thin-walled, greatly elongated and much branched ducts (FIG. 37) containing a milky juice, known as *latex* (see p. 157). Laticiferous ducts are of two kinds; latex vessels and latex cells. They contain numerous nuclei which lie embedded in the thin layer of protoplasm lining the cell-wall which is usually thin and made of cellulose. They occur irregularly distributed in the mass of parenchymatous cells, and their function also is not clearly understood. They may act as food storage organs or as reservoirs of waste products. They may also act as translocatory tissues.

Latex vessels (FIG. 37B) are the result of fusion of many cells. They are formed from rows of elongated meristematic cells from which partition walls soon get dissolved, as in wood vessels. They grow more or less as parallel ducts, and in the mature portion of the plant they anastomose with one another *by the fusion of their branches, forming a network*. Latex vessels are found in poppy family, e.g. opium poppy, garden poppy and prickly poppy, and also in some species of sunflower family or *Compositae*, e.g. *Sonchus*.

Latex cells (FIG. 37A), on the other hand, although much branched like the latex vessels, are really single or independent units. They originate as minute structures and then with the growth of the plant

elongate and branch, ramifying in all directions through the tissues of the plant, but *without fusing together to form a network.* They are

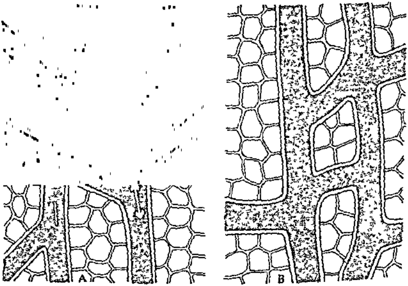


FIG. 37. Laticiferous Tissue. *A*, latex cells; *B*, latex vessels.

coenocytic in nature (see p. 167). Latex cells are found in madar (*Calotropis*), spurges (*Euphorbia*), oleander (*Nerium*), yellow oleander (*Thevetia*), periwinkle (*Vinca*), *Ficus* (e.g. banyan, fig, peepul), etc.

apart. Some slender threads will be seen to come out. Mount them carefully in

that the latex cells lie embedded in parenchyma, as shown in FIG. 37A.

lying embedded in other tissues in the interior of the plant body. They are parenchymatous in nature, and contain abundant protoplasm with a large nucleus. They contain different substances and have manifold functions.

Internal glands are (1) oil-glands (FIG. 38A) secreting essential oils, as in the fruits and leaves of orange, lemon, pummelo, etc.; (2) mucilage-secreting glands, as in the betel leaf; (3) glands secreting gum, resin, tannin, etc. (see FIG. 26); (4) digestive glands secreting enzymes; and (5) water-secreting glands, known as hydathodes.

Hydathodes (FIG. 39) are special structures through which exudation of water takes place in liquid form. They are mainly found in aquatic plants and in some

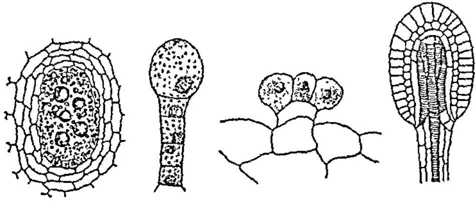


FIG. 38. Glands. *A*, an oil-gland of orange rind; *B*, a glandular hair of *Boerhaavia* fruit; *C*, a digestive gland of butterwort; *D*, a digestive gland of sundew.

herbaceous plants growing in moist places. They occur at the tip of the leaf or on its margin at the apices of veins and are made of a group of living cells having numerous intercellular spaces filled with water, but few or no chloroplasts. They represent modified bundle-ends. These cells, called *epithem cells*, open out into one or more sub-epidermal chambers; these in turn communicate with the exterior through an open water stoma or water pore. The water stoma structurally resembles an ordinary stoma (see p. 185), but is usually larger and has lost the power of movement. Hydathodes are commonly seen in water lettuce (*Pistia*), water hyacinth, garden nasturtium, rose, balsam, aroids, many grasses, etc.

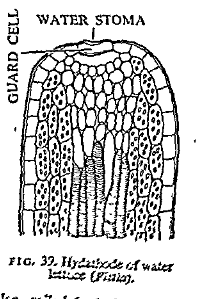


FIG. 39. Hydathode of water lettuce (*Pistia*).

External glands occur as outgrowths and are in the nature of short hairs tipped by glands, known as glandular hairs. External glands are: (1) water-secreting hairs or glands, also called hydathodes; (2) glandular hairs (FIG. 38B) secreting gummy substances, as in tobacco, *Plumbago* (B. CHITA; H. CHITRAK), and *Boerhaavia* (B. PUNARNAVA; H. THIKRI); (3) glandular hairs secreting irritating, poisonous substances, as in nettles (FIG. I/73); (4) nectar-secreting glands or nectaries, as in many flowers; and (5) enzyme secreting glands (FIG. 38 C-D), as in carnivorous plants.

Distribution of Strengthening or Mechanical Tissues. The distribution of mechanical tissues in the plant body is determined by several factors. From a purely mechanical standpoint the principle of distribution is as follows. Stems have to bear the weight of the upper parts, and are swayed back and forth by the wind. They are, therefore, subjected to alternate stretching and compressing. The best position for strengthening tissues in stems, therefore, is close to the periphery, either in the form of a cylinder or in patches. In dicotyledons it is of utmost importance that the mechanical tissues do not obstruct secondary growth in thickness. In them, therefore, sclerenchyma occurs advantageously in the form of separate strands. The hypodermal collenchyma in them is a decided advantage since it gives necessary strength and flexibility and at the same time it helps secondary

or in the form of a sheath encasing each vascular bundle or in the form of a circular band in the cortical region, as in *Asparagus*. Roots, on the other hand, are subjected to the pulling force exerted by the swaying stem and also to the compressing force exerted by the surrounding soil. These forces are met by roots by the development of a solid wood cylinder in or around the centre.

Collenchyma and sclerenchyma including fibres, wood fibres, and bast fibres are the two most important tissues concerned in the strengthening of the plant body. Of these the distribution of collenchyma has been already discussed (see p. 172). In stems sclerenchyma is distributed in various parts. It may occur as (1) hypodermis, particularly in woody dicotyledons, many monocotyledons and ferns; (2) isolated strands in the cortex, as in the palm stem; (3) a few definite layers in the pericycle, as in the *Cucurbita* stem; (4) irregular patches in the pericycle; (5) patches lying associated with the phloem of the vascular bundle, and constituting the hard bast, as in the sunflower stem; (6) a continuous zone extending from one vascular bundle to another, as often seen in lily family or *Liliaceae*; (7) wood fibres associated with wood or xylem; (8) bast fibres, more particularly in secondary phloem; and (9) bundle sheath encircling a vascular bundle, as in many monocotyledons.

Roots less frequently develop sclerenchyma, and they are wanting in collenchyma. Here the lignified wood vessels and tracheids give the necessary strength. Later on wood fibres develop in the secondary wood and contribute materially to the mechanical strength of the root. In some dicotyledonous roots, as in broad bean (*Vicia*), hard bast is present. In many monocotyledonous roots, as in aroids, the pith is sclerenchymatous. Sometimes, as in orchids, the conjunctive tissue is also sclerenchymatous.

For distribution of sclerenchyma in the leaf see p. 212.

meristem. At the apex it is single-layered but lower down it becomes multi-layered. It forms the cortex of the stem, which is often, particularly in dicotyledons, differentiated into hypodermis, general cortex and endodermis.

(3) **Plerome** (*pleres*, full). This lies internal to the periblem, and is the central region of the stem apex. At a little distance behind the apex c

These

bium.

bundles of vessels and sieve-tubes, i.e. into vascular bundles. A portion, however, remains undifferentiated, and it forms the cambium of the vascular bundle. Plerome is differentiated into the pericycle, medullar rays, pith and vascular bundles (derived from the procambial strands), and forms the central cylinder or *stele* of the stem.

2. **Root Apex** (FIG. 41). A median longitudinal section through the apex of the root shows that it is covered over and protected by a many-layered tissue which constitutes the **root-cap**. The apical meristem or growing region lies behind the root cap (see FIG. 1/3). The promeristem, as in the stem, early differentiates into three regions, viz. (1) dermatogen, (2) periblem, and (3) plerome. In many roots, however, these three regions are not clearly marked

(1) **Dermatogen.** As in the stem, this is also single-layered, but at the apex it merges into the periblem; just outside this the dermatogen cuts off many new cells, thus forming a small-celled tissue, known as the **calyptrogen** (*calyptra*, cap; *gen*, producing). The calyptrogen is also meristematic, and by repeated divisions of its cells gives rise to the **root-cap**. As the root passes through the hard soil, the root-cap often wears away

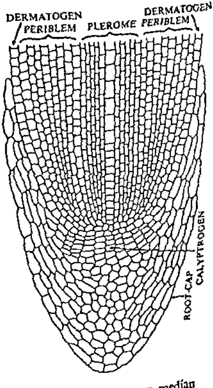


FIG. 41. Root apex in median longitudinal section.

plants

in the soil more easily. The root-cap is absent from aquatic plants, although an analogous structure, called *root-pocket*, is conspicuous in many of them (see p. 3). Sometimes, as in dicotyledons generally, the dermatogen continues upwards as a single outermost layer (epiblema) of the root; but in monocotyledons generally the dermatogen is exhausted in the formation of the root-cap so that the outermost layer of the root is derived from the outermost layer of the periblem. At a little distance from the root-tip the outermost layer bears a large number of *unicellular root-hairs*. Root-hairs are mostly absent from aquatic plants.

(2) **Periblem.** As in the stem, this is also single-layered at the apex and many-layered higher up. In monocotyledons generally the outermost layer of the periblem forms the outermost layer of the root. Periblem forms the middle region or cortex of the root.

(3) **Plerome.** The plerome's structure and function are practically the same as those of the stem. But here some procambial strands give rise to bundles of vessels (xylem) and others to bundles of sieve-tubes (phloem) in an alternating manner (see FIG. 48).

Theories regarding Apical Meristem. (*a*) **Apical cell theory.** Nageli (1858) first coined the term 'meristem' and said that the apical meristem consisted of a single apical cell in all plants While this is true of many cryptogams, it is not applicable to phanerogams. (*b*) **Histogen theory.** In 1870 Hanstein formulated his histogen theory. According to this the apical meristem of angiosperms is divisible into dermatogen, periblem and plerome giving rise to epidermis, cortex and stele respectively. (*c*) **Tunica-corpus theory.** In 1924 Schmidt proposed the tunica-corpus theory. According to this theory there are two zones in the apical meristem. *Tunica* is the outer zone consisting of one or more peripheral layers of cells normally showing anticlinal divisions, and corpus is the undifferentiated mass of cells enclosed by the tunica; its cells divide in many planes. The epidermis arises from the outer layer of tunica, while the remaining tissues arise from the corpus (or partly from the tunica).

Haberlandt (1914) introduced another system to explain the differentiation of the apical meristem. According to Haberlandt the promeristem differentiates into protoderm which gives rise to the epidermal tissue system, procambium which gives rise to the vascular tissue system, and ground meristem which gives rise to the ground tissue system.

Chapter 3 THE TISSUE SYSTEM

of tissues which may structurally be of like or different nature, but perform a common function and have the same origin. The three systems are: (I) the epidermal tissue system, (II) the ground or fundamental tissue system, and (III) the vascular tissue system.

I. THE EPIDERMAL TISSUE SYSTEM

Epidermis. The epidermal tissue system is derived from the dermatogen of the apical meristem and forms the **epidermis** (*epi*, upon; *derma*, skin) or the outermost skin layer which extends over the entire surface of the plant body, and is continuous except for certain openings (stomata and lenticels). At surface view the cells of the epidermis are somewhat irregular in outline (see FIG. 42) varying in shape and size, but closely fitted together without intercellular spaces. They, however, appear more or less rectangular in cross-section. Epidermis is mostly single-layered, but sometimes, as in the leaves of India-rubber plant, banyan, oleander, etc., it becomes few-layered, called *multiple epidermis*. Epidermal cells are parenchymatous in

numerous stomata through which an interchange of gases takes place between the plant and the atmosphere. Epidermal cells soon die off and are filled with various substances such as tannin, silica particles, gum, mucilage, crystals, etc. Inner and radial walls of epidermal cells are thin, while the outer walls are thick and usually impregnated with cutin or suberin. Cutinization or suberization sometimes extends to the radial walls also. The cutinized layer called the cuticle acts as a hard varnish-like coating and protects the inner cells against loss of water, mechanical injury and potential parasites (see next page). Excretion of wax in the form of rods, scales, grains, etc., prevents further loss of water. In many plants epidermal cells often bear outgrowths, known as **hairs** or **trichomes**. These may be unicellular or ... stiff. Besides,

... THIKRI), tobacco, *Plumbago* (B. CHITA; H. CHITRAK), etc. A dense coating of hairs, or development of scales, rods, etc., on the epidermal surface is another feature of the epidermis in many plants.

The outermost layer of the root is called the **epiblema** or **piliferous layer**. It is mainly concerned with the absorption of water and mineral salts from the soil. Thus to increase the absorbing surface which has been estimated to be 5 to 20 times greater the outer walls of most of its cells extend outwards and form tubular unicellular prolonga-

tions called the **root-hairs**. The epiblema is neither cutinized nor is it provided with stomata.

Functions. (1) The primary function of the epidermis is the protection of the internal tissues against mechanical injury, excessive heat or cold, fluctuations of temperature, attack of parasitic fungi and bacteria, and against leaching effect of rain; this is due to the presence of cuticle, hairs, tannin, gum, etc. (2) Prevention of excessive evaporation of water from the internal tissues by the development of thick cuticle, wax and other deposition, cutinized hairs, scales, multiple epidermis, etc., is another important function of the epidermis. [illegible] hairs. (4) The epidermis has also to protect the plant against the attack of herbivorous animals; this the epidermis does with the help of sharp and stiff hairs as in some cucurbits, a dense coating of hairs as in *Gnaphalium*, stinging hairs as in nettles (see FIG. I/79), glandular hairs as in *Boerhaavia* (see FIG. 38B), silica particles as in many [illegible] minor functions such as photosynthesis, secretion, etc.

Stomata. *Structure and Behaviour*. Stomata (*stoma*, a mouth) are very minute openings (FIG. 42) formed in the epidermal layer in green

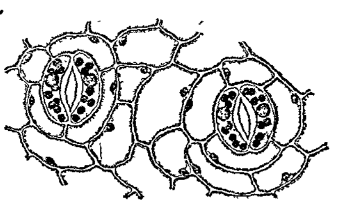


FIG. 42. Stomata (surface view) in epidermal layer.

aerial parts of the plant, particularly the leaves. Roots and non-green parts of the stem are free from them. Each stoma is surrounded by two semi-lunar cells, known as the *guard cells*. The term 'stoma' is often applied to the stomatal opening plus the guard cells. The guard cells are living and always contain chloroplasts, and their inner walls are thicker and outer walls thinner. They guard the stoma or the passage, i.e. they regulate the opening and closing of it like lips. Sometimes the guard cells are surrounded by two or more cells which

are distinct from the epidermal cells; such cells are called *accessory cells*. In dicotyledonous leaves the stomata remain scattered, while in monocotyledonous leaves they occur in parallel rows. Under normal conditions the stomata remain closed at night, i.e. in the absence of light, and they remain open during the daytime, i.e. in the presence of light. In most plants the stomata open fully only in bright light, but in certain plants the stomata do so in diffuse light. Commonly they open fully in the morning and close towards the evening. They may close up at daytime when very active transpiration (evaporation of water) takes place from the surface of the leaf under certain conditions such as dryness of the air, blowing of dry wind and deficient supply of water in the soil. The intensity of light markedly affects the degree of stomatal opening. The opening and closing of the stomata are due to the movement of the guard cells. When the guard cells become turgid, i.e. full of water, they expand and bulge out in the outward direction, and the stoma is open; when the guard cells become flaccid by losing water the stoma is closed.

[illegible]

cells and become turgid, and the stoma opens. In darkness on the other hand the sugar present in the guard cells becomes converted into starch—an insoluble compound. The concentration of the cell-sap is, therefore, lower than that of the neighbouring cells. Under this condition the guard cells lose water and shrink and the stoma closes. The transformation of sugar into starch at night and vice versa at daytime is due to acidity and alkalinity of the cell-sap of the guard cells. At night photosynthesis being in abeyance carbon dioxide accumulates in the guard cells and the cell contents become weakly acid. Under this condition sugar becomes converted into starch. During the daytime carbon dioxide is utilized in photosynthesis and thus the cell contents become slightly alkaline. Under this condition the starch becomes converted into sugar.

There is another hypothesis, called colloidal hypothesis, put forward to explain the movement of the guard cells. According to this, the cell contents become alkaline as a result of the effect of sunlight on guard cells and this causes the colloids present in them to swell, apart from the fact that this causes the transformation of starch into sugar. The swelling of the colloids according to this theory causes the guard cells to bulge out and the stoma to open. At night the acidity of the guard cells increases and causes the colloids to shrink again, and thus to close the stoma, apart from the fact that this increased acidity brings about the conversion of sugar into starch.

Functions and Distribution. Stomata are used for interchange of gases between the plant and the atmosphere—oxygen for respiration and carbon dioxide for manufacture of carbohydrates. For the facility of diffusion of these gases each stoma opens internally into a small cavity, known as the *respiratory cavity* (FIG. 43B) which in its turn communicates with the system of intercellular spaces and air

cavities. Stomata are also the organs through which evaporation of water normally takes place, and the plant thus gets rid of the excess quantity. Stomata are most abundant in the lower epidermis (FIG. 43A) of the dorsiventral leaf (see p. 43); none (or sometimes comparatively few) are present in the upper (FIG. 43C), e.g. in sunflower

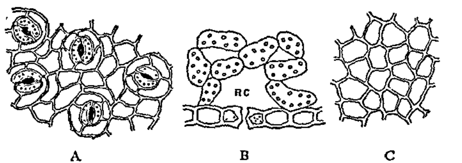


FIG. 43. Stomata in betel leaf. *A*, lower epidermis with numerous stomata (surface view); *B*, section of leaf (a portion of the lower side); *RC*, respiratory cavity internal to a stoma; *C*, upper epidermis with no stoma (surface view).

leaf the average numbers in lower and upper surfaces are 325 & 175, in pea leaf 216 & 101, in gourd leaf 269 & 28, etc. In the isobilateral and centric leaves (see p. 43) stomata are more or less evenly distributed on all sides (see FIGS. 65-66). In the floating leaves, as in those of the water lily, stomata remain confined to the upper e[illegible] alone; in the submerged leaves no stoma is present. In desert plants

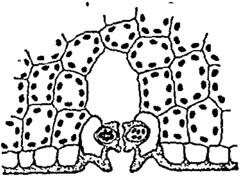


FIG. 44. Sunken stoma in the leaf of American aloe (*Agave*).

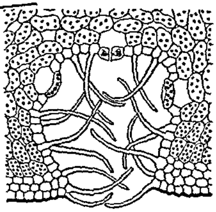


FIG. 45. Sunken stomata in the leaf of oleander (*Nerium*).

and in those showing xerophytic adaptations, e.g. American aloe or century plant (*Agave*; FIG. 44), oleander (*Nerium*; FIG. 45), pine (*Pinus*; see FIG. VI/8), etc., one or more stomata are situated in grooves or pits in the leaf. This is a special adaptation to reduce excessive evaporation, as the stomata sunken in pits are protected from gusts

of wind. The number of stomata per unit area varies within wide limits. In ordinary land plants there is an average of about 100 to 300 stomata per square millimetre, sometimes much less or many more. In the floating leaves of aquatic plants stomata may be as many as 400 per square millimetre; in submerged leaves there are none. In desert plants on the other hand there may be only 10 to 15 stomata per square millimetre; while there are cases with about 1,300 stomata in the same space.

II. THE GROUND OR FUNDAMENTAL TISSUE SYSTEM

This system forms the main bulk of the body of the plant, and extends from below the epidermis to the centre (excluding the vascular bundles). It is partly derived from the periblem and partly from the plerome. Its primary functions are the manufacture and storage of food material; it also has a mechanical function. This system consists of various kinds of tissues, of which parenchyma is most abundant; other tissues are sclerenchyma and collenchyma, and sometimes also laticiferous tissue and glandular tissue. It is differentiated into the following zones and sub-zones.

1. **Cortex.** The cortex is the zone that lies between the epidermis and the pericycle, varying in thickness from a few to many layers. In dicotyledonous stems (see FIG. 52) it is usually differentiated into the following sub-zones: (*a*) **hypodermis**—a few layers of collenchyma or sometimes sclerenchyma; (*b*) **general cortex** or cortical parenchyma—a few layers of thin-walled parenchymatous cells with or without chloroplasts, but often with intercellular spaces; and (*c*) **endodermis**—a single wavy layer, not often very conspicuous; it is also called *starch sheath* as it often has numerous starch grains. In monocotyledonous stems (see FIG. 56), owing to the scattered arrangement of vascular bundles, the cortex is not marked out into the cortex proper and the endodermis; sclerenchyma is, however, often present as hypodermis. In roots (see FIG. 60) the cortex consists of (*a*) many layers of thin-walled parenchymatous cells (general cortex) often with conspicuous starch grains in them, and leaving a lot of intercellular spaces between them, (*b*) a distinc[illegible]

of vertically elongated cells; in cross section the endodermis appears as a single layer of barrel-shaped cells without intercellular spaces. The layer is wavy in stems and often not readily distinguishable or even altogether wanting; while in roots it is circular and well defined. The cells are living containing abundant protoplasm, large nuclei and often starch grains—hence this layer is also called **starch sheath**. Some cells of the endodermis may contain mucilage, tannin, gum, etc. The outer walls of endodermal cells are thin, while radial and inner walls are often thickened, being suberized or cutinized and also sometimes lignified, particularly in roots. The thickened walls are provided with numerous simple pits. Sometimes the thickening takes the form of a band or strip surrounding each cell; this band, first recognized by Caspary in 1865, is called the **Casparian strip**. It may be made of lignin or suberin. Among the thick-walled cells of the endodermis, as in many roots, often occur, opposite to protoxylem vessels, some small thin-walled cells; these are called **passage cells** (see FIG. I/25). Through them the sap absorbed by root-hairs enters the xylem vessels. Endodermis is well developed in the roots of all plants, in the stems of pteridophytes and herbaceous dicotyledons, and in the leaves of gymnosperms; it is, however, absent or indistinct in the stems of woody plants and in the leaves of angiosperms.

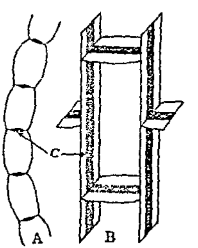


FIG. 46. Casparian strip (*C*) in endodermis; *A*, the latter in transection; *B*, diagram of an endodermal cell.

Functions. Functions of the endodermis are somewhat obscure. Some regard it as a water-tight jacket between the xylem and the surrounding tissues. It may act as an air-dam preventing diffusion of air into the vessels and thus clogging them. It may be a 'diffusion layer' preventing loss of water, mineral salts and food from the vascular bundles. It may be a storage tissue containing starch grains, as in dicotyledons. It may be connected with the osmotic pressure that develops in the root-cortex. It may serve as a passage for water from the cortex of the root to the protoxylem.

2. **Pericycle.** This forms a multi-layered zone between the endodermis and the vascular bundles and occurs as a cylinder encircling the vascular bundles and the pith, as in dicotyledonous stems. It may consist wholly of sclerenchyma forming a continuous zone, as in gourd (*Cucurbita*) stem but more commonly it is made of both parenchyma and sclerenchyma, the latter forming isolated strands

in it (the pericycle). Each such strand associated with the phloem or bast of the vascular bundle in the form of a cap is known as the **hard bast**, as in sunflower stem. In the roots and stems of some aquatic plants the pericycle is absent, and it is not distinguishable in the monocotyledonous stems. In roots the pericycle consists of a single layer of small, very thin-walled, more or less barrel-shaped cells but in many monocotyledons it may be multi-layered and even lignified.

Functions. In all roots the pericycle is the seat of origin of lateral roots (see FIG. 63). In dicotyledonous roots it further gives rise to secondary meristems—a portion of the cambium (see FIG. 72) and later the whole of the cork-cambium (see FIG. 74). In all stems the pericycle is the seat of origin of adventitious roots. Otherwise its functions are mechanical, secretion, storage, etc.

3. **Pith and Pith Rays.** The **pith** or **medulla** forms the central core of the stem and the root and is usually made of large-celled parenchyma with abundant intercellular spaces. In the dicotyledonous stem the pith is often large and well developed, while in the monocotyledonous stem, owing to scattered distribution of vascular bundles, it is not distinguishable; in the dicotyledonous root the pith is either small or absent, bigger vessels having met in the centre; while in the monocotyledonous root a distinct pith is present. It is often parenchymatous, but sometimes sclerenchymatous. In the dicotyledonous stem the pith extends outwards to the pericycle between the vascular bundles. Each extension which is a strip of parenchyma is called the **pith ray** or **medullary ray**. It is not present as such in the root. The cells of the pith and the pith ray are usually larger than those of the cortex and enclose numerous intercellular spaces.

Functions. They serve to store food material. The function of the sclerenchymatous pith is, of course, mechanical. The medullary ray

III. THE VASCULAR TISSUE SYSTEM

This system consists of a number of vascular bundles which are distributed in the stele. The stele is the central cylinder of the stem and the root (and the pine leaf) surrounded by the endodermis and consists of vascular bundles, pericycle, pith and medullary rays. Each bundle is made up of **xylem** and **phloem** with a cambium, as in dicotyledonous stems, or without a cambium, as in monocotyledonous stems, or of only one kind of tissue—xylem or phloem, as in roots. The function of this system is to conduct water and raw food materials from the roots to the leaves, and prepared food materials from the leaves to the storage organs and the growing regions. The ele-

[illegible] of a vascular bundle are [illegible] of the plerome, which show a [illegible] stage. The vascular bundles may be [illegible] in the stems of dicotyledons, gymnosperms [illegible] may be [illegible] in the ground tissue [illegible] cotyledons.

Elements of a Vascular Bundle (FIG. 47). [illegible] cotyledonous stem, when fully formed, [illegible] tissues: (1) xylem or wood, (2) phloem or [illegible] They have different kinds of [illegible]

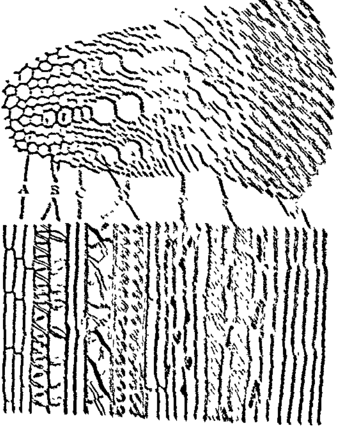


FIG. 47. Vascular bundles of sunflower stem in transverse and longitudinal sections. *A*, wood parenchyma; *B*, protoxylem (annular and spiral vessels); *C*, tracheids and wood fibres; *D*, metaxylem (reticulate and pitted vessels); *E*, cambium; *F*, phloem (sieve-tubes, companion cells and phloem parenchyma); *G*, sclerenchyma (hard bast).

(1) Xylem or Wood. This lies towards the centre, and is composed of the following elements: (1) tracheae or vessels, (2) some tracheids, (3) a number of wood fibres, and (4) a small patch of wood parenchyma. Vessels are of various kinds [illegible] such as spiral [illegible] or bordered [illegible] Wood fibres and wood parenchyma are ordinary sclerenchymatous and paren-

chymatous cells lying associated with the wood or xylem. They are provided with simple pits in their walls. Sometimes in the secondary xylem the wood parenchyma becomes thick-walled and lignified. Xylem vessels and tracheids are used for the conduction of water and mineral salts from the roots to the leaves and other parts of the plant; xylem parenchyma assists them in their task and also serves for food storage, and wood fibres give proper rigidity to the xylem. Except for the wood parenchyma all the other elements of xylem are dead and lignified, and hence their secondary function is to give mechanical strength to the plant.

The first-formed xylem or **protoxylem** consists of *annular*, *spiral* and *scalariform* vessels; it lies towards the centre of the stem and its vessels have smaller cavities. The later-formed xylem or **metaxylem** consists of *reticulate* and *pitted* vessels and some *tracheids*. It lies away from the centre and its vessels have much bigger cavities. Of course all transitional stages are noticed between protoxylem and metaxylem. The development of xylem is *centrifugal* in the stem, of [illegible]

[illegible]

simple pits, particularly in the walls lying against the sieve-tubes. Phloem as a whole is used for translocation of prepared food materials from the leaves to the storage organs and also to the different growing regions. Sieve-tubes carry proteins and many carbohydrates, phloem parenchyma conducts amines and amino-acids and soluble carbohydrates, and companion cells transmit many of the soluble food materials sideways to the surrounding tissues. All the elements of phloem are made of cellulose, and are living. Primary phloem hardly ever contains bast fibres but it may be capped by a patch of sclerenchyma, called the *hard bast*, as seen in the sunflower stem (see FIG. 52).

The outer portion of phloem consisting of narrow sieve-tubes constitutes the **protophloem**, and the inner portion consisting of bigger sieve-tubes constitutes the **metaphloem**.

(3) **Cambium.** This is a thin strip of primary meristem lying in between xylem and phloem. It consists of one or a few layers of thin-walled and roughly rectangular cells. Although cambial cells look rectangular in transverse section, they are much elongated with often oblique ends. They become flattened tangentially, i.e. at right angles to the radius of the stem.

Note. The wood of gymnosperms and ferns consists exclusively of tracheids; [illegible]

[illegible]

of plants. In monocotyledons there is seldom any phloem parenchyma [illegible]

found, cambium is also absent from them. In all roots xylem forms one bundle, and phloem another.

Types of Vascular Bundles. According to the arrangement of xylem and phloem, the vascular bundles are of the following types:

(1) **Radial**, when xylem and phloem form separate bundles and these lie on different radii alternating with each other, as in roots (FIG. 48). The radial bundle is the most primitive type of all vascular bundles.

(2) **Conjoint**, when xylem and phloem combine into one bundle. There are different types of conjoint bundles.

(*a*) **Collateral**, when xylem and phloem lie together on the same radius, xylem being internal and phloem external. When in a colla-

FIG. 48.

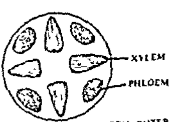
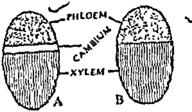
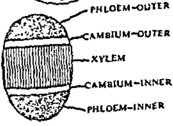


FIG. 49.





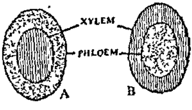


FIG. 50. FIG. 51.

Types of Vascular Bundles. FIG. 48. Radial. FIG. 49. Collateral—*A*, open; *B*, closed. FIG. 50. Bicollateral. FIG. 51. Concentric—*A*, xylem central (amphicribral); *B*, phloem central (amphivasal).

teral bundle the cambium is present, as in all dicotyledonous stems, the bundle is said to be *open* (FIG. 49A), and when the cambium is absent it is said to be *closed* (FIG. 49B), as in monocotyledonous stems.

(*b*) **Bicollateral** (FIG. 50), when in a collateral bundle both phloem and cambium occur twice—once on the outer side of xylem and then again on the inner side of it. The sequence is outer phloem, outer cambium, xylem, inner cambium and inner phloem. Bicollateral bundle is characteristic of *Cucurbitaceae*; it is also often found in *Solanaceae*, *Apocynaceae*, *Convolvulaceae*, *Myrtaceae*, etc. A bicollateral bundle is always open.

(*c*) **Concentric**,

is surrounded by

to whether one is

the centre and is surrounded by xylem (FIG. 51B), as in some monocotyledons, e g. dragon plant (*Dracaena*; see FIG. 75), dagger plant (*Yucca*; see FIG. I/78), *Cordyline*, sweet flag (*Acorus*; B. & H. BOCH), etc., the co
other hand
(FIG. 51A),
tic angiosperms, the concentric bundle is said to be amphicribral. A concentric bundle is always closed.

Primary Meristems and Tissue Systems

PROMERISTEM → dermatogen → epidermis → epidermal tissue system ← protoderm ← PROMERISTEM

PROMERISTEM → periblem → cortex → hypodermis, general cortex, endodermis

pericycle, pith ray, pith → ground tissue system ← ground meristem ← PROMERISTEM

PROMERISTEM → plerome → stele → pericycle, pith ray, pith; vascular bundles (phloem, cambium and xylem) → vascular tissue system ← procambium ← PROMERISTEM

Chapter 4 ANATOMY OF STEMS

Double Staining and Permanent Preparation of Microscopic Sections. For free-hand sections of ordinary material such as stem, root and leaf the following pro-

uniform sections can be properly stained.

fied elements deep red, while haematoxylin stains cellulose elements pur—
The schedule given on the next page may be followed.

[1] Haberlandt uses the term *hadrome* for xylem, and the term *leptome* for phloem. Accordingly an amphivasal bundle is said to be hadrocentric, and an amphicribral bundle leptocentric.

1. Safranin—5-10 minutes. 2. Washing in water (or 50% alcohol)—5 minute (to remove most of the stain from cellulose elements). 3. Haematoxylin (bette diluted)—1-2 minutes, the stain deepens in water at the next stage. 4. Washing in water—a few minutes. 5. Dehydration (by passing through grades of alcohol —30%, 50%, 75%, 85% or 90% and 100% (absolute alcohol)—1 minute in each with another change in 100% for 1 minute to dehydrate completely. Note tha incomplete dehydration will result in fogginess at the next stage. 6. Clove oil— 2-5 minutes or more. Clove oil is a clearing reagent. 7. Canada balsam (dissolved in xylol)—mount a section in it on a clean slide (after removing excess clove oi from the section with a piece of blotting paper). 8. Cover the section with a cover-glass by gently sliding it down. 9. Label and keep the slide flat for drying up away YOUN from dust.

B. **Safranin and Light Green.** Safranin stains lignified elements deep red, while light green stains cellulose elements bright green. This is a good combination of stains and easy to manipulate. There is least chance of overstaining also. Follow the schedule as given below.

1. Safranin, as above. 2. Washing in water. 3. Dehydration, as above. 4. Light Green (in clove oil)—3-5 minutes (0.2 gm. of light green powder dissolved in 50 c.c. of absolute alcohol and 50 c.c. of clove oil). 5. Clove oil or xylol—1-2 minutes. 6. Canada balsam and the rest, as above.

Maceration. By this method the tissues may be separated into individual cells. The principle lies in dissolving the middle lamella (made of pectic compounds) and then teasing out the cells. The procedure is as follows (Schultze's method). Cut the material into small pieces to the thickness of match-sticks and put them into a test-tube. Pour strong nitric acid just enough to cover the pieces; then add a few crystals of potassium chlorate. Heat gently (in an open space to avoid disagreeable fumes) for 4 or 5 minutes until the fumes have ceased. Pour out the contents into water in a dish or beaker and wash the pieces thoroughly in water. For examination a piece may be placed on a slide, crushed under cover-glass and then teased with needles. Stain and mount in glycerine. Cover and examine the isolated elements. The washed pieces may be preserved in 3-4% formalin for future use.

Dicotyledonous Stems

I. YOUNG SUNFLOWER STEM (FIG. 57).

2. **Cortex.** This lies below the epidermis and consists of external collenchyma, central parenchyma and internal starch sheath or endodermis (*a*) **Hypodermis** (collenchyma)—this lies immediately below the epidermis. and consists of some 4 or 5 layers of collenchymatous cells These cells are specially thickened at the corners against the intercellular spaces. The thickening is due to a deposit of cellulose impregnated with pectin. The cells are living and contain a number of chloroplasts. (*b*) **General cortex or cortical parenchyma**—this lies internal to the hypodermis and consists of a few layers of thin-walled,

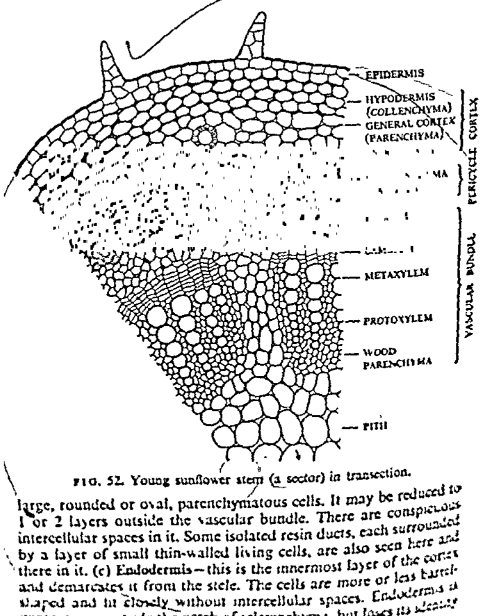


FIG. 52. Young sunflower stem (a sector) in transection.

large, rounded or oval, parenchymatous cells. It may be reduced to 1 or 2 layers outside the vascular bundle. There are conspicuous intercellular spaces in it. Some isolated resin ducts, each surrounded by a layer of small thin-walled living cells, are also seen here and there in it. (*c*) **Endodermis**—this is the innermost layer of the cortex and demarcates it from the stele. The cells are more or less barrel-shaped and fit closely without intercellular spaces. Endodermis is conspicuous outside the patch of sclerenchyma, but loses its identity

on either side. It almost invariably contains numerous starch grains and is also known as the *starch sheath*.

3. **Pericycle.** This is the region lying in between the endodermis and the vascular bundles, and is represented by semi-lunar patches of sclerenchyma and the intervening masses of parenchyma. Each patch lying associated with the phloem of the vascular bundle is called the **hard bast**. The middle lamella is very prominent in this tissue.

4. **Medullary Rays.** A few layers of fairly big polygonal or radially elongated cells, lying in between two vascular bundles, constitute the medullary rays.

5. **Pith.** This is very elaborate in the sunflower stem, and occupies the major portion of it. It extends from below the vascular bundles to the centre, and is composed of rounded or polygonal, thin-walled living cells with conspicuous intercellular spaces between them.

6. **Vascular Bundles.** These are collateral and open, and are arranged in a ring. Each bundle is composed of (1) **phloem** or **bast**, (2) **cambium** and (3) **xylem** or **wood**.

(1) **Phloem.** This lies externally and is composed only of thin and cellulose-walled elements. It consists of (*a*) **sieve-tubes** which appear as slightly larger cavities than the rest of the phloem. On the whole the *sieve-tubes of the sunflower stem are very narrow*. Associated with each sieve-tube may be seen a smaller cell; this is (*b*) the **companion cell**. The rest of the phloem is packed with small-celled parenchyma known as (*c*) the **phloem parenchyma**. All the phloem elements are living, and contain various kinds of food material.

(2) **Cambium.** Passing inwards, a band of thin-walled tissue is seen, whose cells are regularly arranged in radial rows and are roughly rectangular in shape, very small in size and thin walled. (If the section be cut through a comparatively old portion of the stem the cambium is seen to be continuous from one vascular bundle to another, and the division of its cells noted both inside and outside. This indicates the beginning of secondary growth.)

(3) **Xylem or Wood.** This lies internally and consists of the following elements: (*a*) ***Wood Vessels.*** Some large cavities, arranged in a few radial rows, can be easily recognized in the wood; these are the wood vessels. The smaller vessels constituting the *protoxylem* lie towards the centre, and the bigger ones constituting the *metaxylem* lie away from the centre. Protoxylem consists of annular, spiral and scalariform vessels, and metaxylem of reticulate and pitted vessels. Their walls are always thick and lignified. (*b*) **Tracheids.** Surrounding the metaxylem vessels and lying in between them some small, thick-walled cells can be seen; these are the tracheids. In transverse section of the stem they are hardly distinguishable from the wood fibres which

lie mixed up with them. (*c*) Wood Fibres. These appear somewhat irregular and polygonal in section. They are thick-walled and lignified, and stained like the wood vessels. Excepting the vessels nearly the whole of the wood is packed with these elements. (*d*) Wood Parenchyma. A patch of parenchymatous cells is to be seen on the inner side of the bundle surrounding the protoxylem; this is the wood parenchyma. The cells of the wood parenchyma retain their protoplasm.

II. INDIAN BUTTERCUP STEM (FIG. 53)
(*Ranunculus sceleratus*)

Note the zones, sub-zones and nature of tissues as labelled against the sketch. Note also that a number of air-cavities develop in the

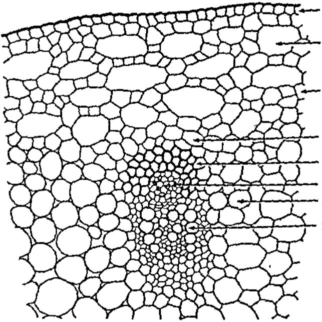


FIG. 53. *Ranunculus* stem (a sector) in transection. Note that the cambium is absent or very feebly developed.

cortex (the plant being sub-aquatic in habit) and that the cambium is absent; some feebly-developed cambium-like cells represent the remnant of the procambium. Study the tissues in detail.

III. YOUNG GOURD STEM (FIGS. 54-5)
(*Cucurbita*)

Note that it is hollow, and has usually five ridges and five furrows, and that the vascular bundles are usually ten in number and arranged

in two rows, those of the outer row corresponding to the ridges and those of the inner to the furrows (FIG. 54). Then study the tissues in detail (FIG. 55).

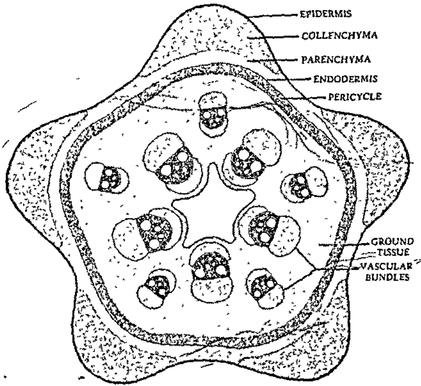


FIG. 54. Young *Cucurbita* stem in transection, as seen under a pocket lens.

1. **Epidermis.** This is the single outermost layer passing over the ridges and furrows; it often bears many long and narrow multicellular hairs.

2. **Cortex.** This consists of hypodermis externally, general cortex or cortical parenchyma in the middle, and endodermis internally. (*a*) **Hypodermis (collenchyma)** lies immediately below the epidermis, and consists of six or seven (sometimes more) layers of collenchymatous cells in the ridges, and in the furrows only two or three layers, sometimes none. Collenchyma contains some chloroplasts. (*b*) **General cortex or cortical parenchyma** forms a narrow zone in the middle, two or three layers thick; in the furrows it passes outwards right up to the epidermis through the collenchyma. Chloroplasts are abundant in it. (c) **Endodermis** is the innermost layer of the cortex, lying immediately outside the pericyclic sclerenchyma. This layer is wavy in outline and contains starch grains.

3. **Pericycle.** Below the endodermis there is a zone of sclerenchyma

which represents the pericycle. This zone consists of four or five layers of thick-walled, lignified cells which are polygonal in shape.

4. Ground Tissue. This is the continuous mass of thin-walled parenchymatous cells extending from below the sclerenchyma to the pith cavity; in this tissue lie embedded the vascular bundles.

5. Vascular Bundles. These are *bicollateral*, usually ten in number, and are arranged in two rows. Each bundle consists of (1) xylem, (2) two strips of cambium, and (3) two patches of phloem.

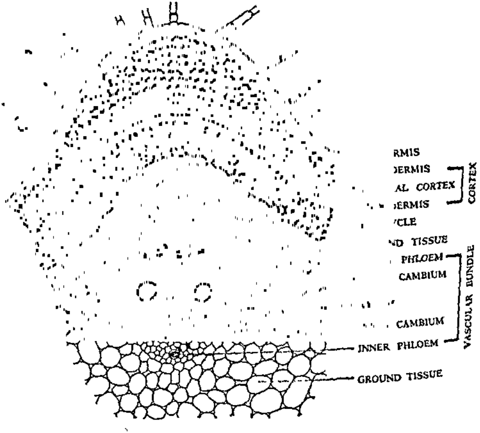


FIG. 55. Young *Cucurbita* stem (a sector) in transection.

(1) **Xylem** occupies the centre of the bundle, and consists, on the outer side, of very wide vessels (pitted) which constitute the *metaxylem*, and on the inner side, of narrower vessels which constitute the *protoxylem*. There may be some tracheids and wood fibres but wood parenchyma is abundant. Vessels are not arranged in radial rows, as in the sunflower stem.

(2) **Cambium.** This tissue occurs in two strips—the outer and the inner, one on each side of xylem, forming a narrow strip between phloem and xylem to the inside, and between xylem and phloem to

the outside; its cells are thin-walled and rectangular, and arranged in radial rows. The outer cambium is many-layered and is more or less flat, and the inner cambium is few-layered and curved.

(3) Phloem occurs in two patches—the outer and the inner. Note that the outer phloem is plano-convex and the inner one semi-lunar in shape. Each patch of phloem consists of sieve-tubes, companion cells, and phloem parenchyma. Sieve-tubes are very conspicuous in the phloem of the *Cucurbita* stem. Here and there sieve-plates with perforations in them may be distinctly seen (see FIGS. 35-6). The rest of the phloem is made up of small, thin-walled cells which constitute the phloem parenchyma.

Monocotyledonous Stems

I. INDIAN CORN OR MAIZE STEM (FIG. 56)

1. **Epidermis.** This is a single outermost layer with a thick cuticle on the outer surface. Here and there in the epidermis a few stomata may be seen.

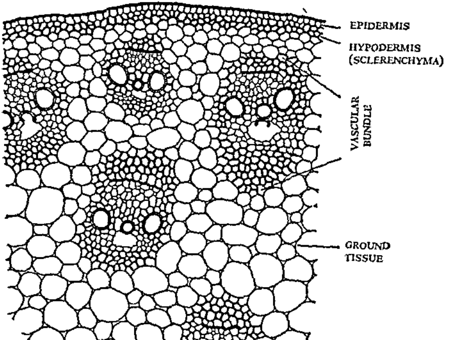


FIG. 56. Maize or Indian corn stem (a sector) in transection.

(pitted) lying laterally together with the small pitted tracheids lying in between them constitute the *metaxylem*. Besides, thin-walled wood (or xylem) parenchyma almost surrounding a conspicuous water-containing cavity is present in the protoxylem; a few wood fibres also occur associated with the tracheids in between the two big pitted vessels. This water-containing cavity has been formed lysigenously, i.e. by the breaking down of the inner protoxylem vessel and the contiguous parenchyma during the rapid growth of the stem.

(2) **Phloem** consists exclusively of sieve-tubes and companion cells; no phloem parenchyma is present in the monocotyledonous stem. The outermost portion of the phloem, which is a broken mass, is the *protophloem*, and the inner portion is the *metaphloem*. The former soon gets disorganized, and the latter shows distinct sieve-tubes and companion cells.

Differences between Dicotyledonous and Monocotyledonous Stems

	Dicotyledonous stem (e g. sunflower)	Monocotyledonous stem (e g. maize)
1 Hypodermis	collenchymatous	sclerenchymatous.
2 General Cortex	a few layers of parenchyma	a continuous mass of parenchyma up to the centre (ground tissue) without differentiation into distinct tissues.
3 Endodermis	a wavy layer	
4 Pericycle	a zone of parenchyma and sclerenchyma	
5 Medullary Ray	a strip of parenchyma in between vascular bundles	
6 Pith	the central cylinder	not marked out.
7 Vascular Bundles	(*a*) collateral and open	collateral and closed.
	(*b*) arranged in a ring	scattered.
	(*c*) of uniform size	larger towards the centre.
	(*d*) phloem parenchyma present	it is absent.
	(*e*) usually wedge-shaped	usually oval.
	(*f*) bundle sheath absent	strongly developed.

II. ASPARAGUS STEM (FIG. 58)

In a transverse section of the stem note the tissues, as labelled against the sketch, and study them in detail.

III. FLOWERING STEM (SCAPE) OF CANNA (FIG. 59)

1. **Epidermis.** This is the outermost layer consisting of a single row of very small, polygonal cells flattened tangentially. The outer walls of the epidermis are cutinized.

2. **Ground Tissue System.** From below the epidermis to the centre

2. Hypodermis (Sclerenchyma). This forms a narrow zone of sclerenchymatous cells, usually two or three layers thick, lying below the epidermis.

3. Ground Tissue. This is the continuous mass of thin-walled parenchymatous cells, extending from below the sclerenchyma to the centre. It is not differentiated into cortex, endodermis, pericycle, etc., as in a dicotyledonous stem. The cells of the ground tissue enclose numerous intercellular spaces.

4. Vascular Bundles (FIG. 57). These are collateral and closed, and lie scattered in the ground tissue; they are more numerous, and lie

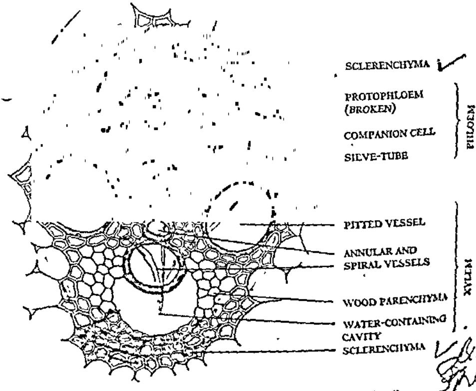


FIG. 57. A vascular bundle of maize stem (magnified).

closer together nearer the periphery than the centre. The peripheral ones are also seen to be smaller in size than the central ones. Each vascular bundle is somewhat oval in general outline and is more or less completely surrounded by a sheath of sclerenchyma which is specially developed on the two sides—upper and lower. The bundle consists of two parts, viz. xylem and phloem.

(1) Xylem mainly consists of usually four distinct vessels arranged in the form of a Y, and a small number of tracheids arranged irregularly. The two smaller vessels (annular and spiral) lying radially towards the centre constitute the *protoxylem*, and the two bigger vessels

the whole mass of tissues, leaving out the vascular bundles, consti-

tissue consisting of one or two layers of chloroplast-bearing cells, intruding inwards here and there, (c) several patches of sclerenchyma of different sizes lying against the chlorophyllous tissue, and (d) ground tissue consisting of a continuous mass of large, thin-walled, parenchymatous cells, containing starch grains and enclosing numerous intercellular spaces between them.

3. **Vascular Bundles.** These are numerous and are of different sizes, lying scattered in the ground tissue. Each bundle is closed and collateral. It is incompletely surrounded by a sheath of sclerenchyma (bundle sheath), with a distinct patch of it on the outer side in the form of a cap, and a thin strip on the inner side; seldom a regular and complete sheath is formed encircling the vascular bundle. Each bundle consists of (a) xylem on the inner side, and (b) phloem on the outer. **Xylem** consists of a large prominent spiral vessel, with often one or two smaller ones, also spiral in nature, lying usually on its outer side, and some parenchyma. **Phloem** consists of sieve-tubes and companion cells.

Chapter 5 ANATOMY OF ROOTS

I. YOUNG DICOTYLEDONOUS ROOT (FIG. 60)

1. **Epiblema or Piliferous Layer.** This is a single outermost layer of thin-walled cells; outer walls of most of these cells extend outwards and form unicellular root-hairs. This layer is used for absorption of water and other solutes from the soil and, therefore, it has no cuticle. Root-hairs increase the absorbing surface of the root.

2. **Cortex.** This consists of many layers of thin-walled rounded cells, with numerous intercellular spaces between them. The cells of the cortex contain leucoplasts and store starch grains. The epiblema is, in some cases, only short-lived; as it dies off, a few outer layers of the cortex become cutinized and form the *exodermis* of the root.

3. **Endodermis.** This is a single ring-like layer of barrel-shaped cells which are closely packed without intercellular spaces. The radial walls of this layer are often thickened, and sometimes this thickening extends to the inner walls also, and not infrequently the walls abutting

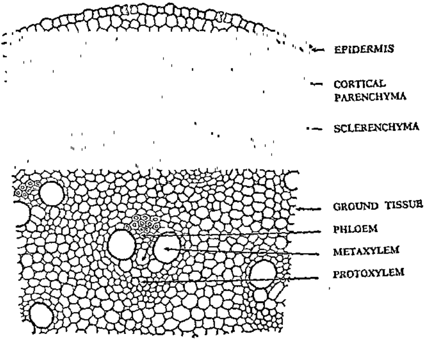


FIG. 58. *Asparagus* stem (a sector) in transection.

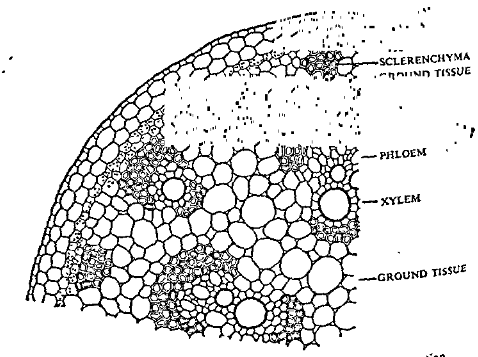


FIG. 59. Flowering stem (scape) of *Canna* (a sector) in transection.

centripetal, or in other words, xylem is said to be *exarch*. The number of xylem (or phloem) bundles varies from two to six (di-, tri-, tetr-, pent-, or hex-arch), very seldom more. The cambium makes its appearance only later as a secondary meristem. **Phloem bundle** consists of sieve-tubes, companion cells and phloem parenchyma. **Xylem bundle** consists of protoxylem which lies towards the circumference abutting on the pericycle, and metaxylem towards the centre. Protoxylem is composed of small vessels (annular and spiral) and metaxylem of bigger vessels (reticulate and pitted). The metaxylem groups often meet in the centre, and then the pith is obliterated (it gets disorganized).

II. MONOCOTYLEDONOUS ROOT (FIG. 61)

1. **Epiblema or Piliferous Layer.** This is the single outermost layer with a number of unicellular root-hairs.

2. **Cortex.** This is a many-layered zone of rounded or oval cells with

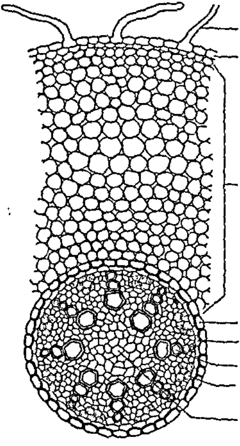


FIG. 61. Monocotyledonous root in transection.

upon the protoxylem are provided with simple pits. Endodermis is the innermost layer of the cortex and occurs as a ring (or cylinder) around the stele. Here and there, particularly lying against the protoxylem, small thin-walled cells are often found in the endodermis; these are the *passage cells*.

4. **Pericycle.** This lies internal to the endodermis, and is a single circular layer like the latter; its cells are very small and thin-walled, but contain abundant protoplasm.

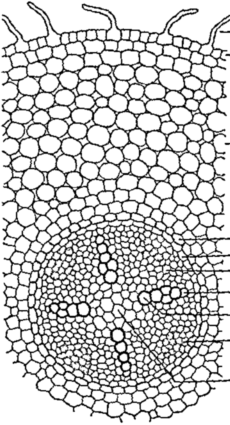


FIG. 60. Young dicotyledonous root (gram seedling) in transection.

5. **Conjunctive Tissue.** The parenchyma lying in between xylem and phloem bundles constitutes the *conjunctive tissue*.

6. **Pith.** This occupies only a small area in the centre of the root. But soon the pith becomes obliterated owing to the wood vessels meeting in the centre.

centripetal, or in other words, xylem is said to be *exarch*. The number of xylem (or phloem) bundles varies from two to six (di-, tri-, tetr-, pent-, or hex-arch), very seldom more. The cambium makes its appearance only later as a secondary meristem. Phloem bundle consists of sieve-tubes, companion cells and phloem parenchyma. Xylem bundle consists of protoxylem which lies towards the circumference abutting on the pericycle, and metaxylem towards the centre. Protoxylem is composed of small vessels (annular and spiral) and metaxylem of bigger vessels (reticulate and pitted). The metaxylem groups often meet in the centre, and then the pith is obliterated (it gets disorganized).

II. MONOCOTYLEDONOUS ROOT (FIG. 61)

1. **Epiblema or Piliferous Layer.** This is the single outermost layer with a number of unicellular root-hairs.

2. **Cortex.** This is a many-layered zone of rounded or oval cells with

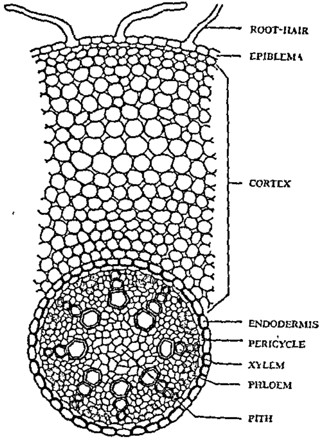


FIG. 61. Monocotyledonous root in transection.

intercellular spaces between them. As the epiblema dies off a few outer layers of the cortex become cutinized and form the *exodermis*.

3. **Endodermis.** This is the innermost layer of the cortex and forms a definite ring around the stele. Radial walls and often the inner walls of the endodermis are considerably thickened. Cells of the endodermis are barrel-shaped. *Passage cells* are often present in this layer, lying against the protoxylem.

4. **Pericycle.** This is the ring-like layer lying internal to the endodermis. Its cells are very small and thin-walled.

5. **Conjunctive Tissue.** The parenchyma in between xylem and phloem bundles is known as the *conjunctive tissue*.

6. **Pith.** The parenchymatous mass of cells in the central portion of the root is the pith. It is well developed in most monocotyledonous roots. In some cases the pith becomes thick-walled and lignified.

7. **Vascular Bundles.** Xylem and phloem form an equal number of *separate bundles, and they are arranged in a ring*. The arrangement is *radial* (see p. 193). Bundles are numerous (polyarch). In exceptional cases, as in onion, they are limited in number. The development of wood is *centripetal*, or, in other words, xylem is said to be *exarch*. **Phloem bundle** consists of sieve-tubes, companion cells and phloem parenchyma. **Xylem bundle** consists of protoxylem which lies abutting on the pericycle, and metaxylem towards the centre, i.e. xylem is exarch Protoxylem consists of annular and spiral vessels, and metaxylem of reticulate and pitted vessels. A few isolated, big vessels may often be seen in the pith.

Differences between Dicotyledonous and Monocotyledonous Roots

	Dicotyledonous root	Monocotyledonous root
1 Xylem bundles	vary from 2 to 6 (di-to hex-arch), rarely more	numerous (polyarch), rarely a *limited number*.
2 Pith	small or absent	*large and well-developed*.
3 Pericycle	gives rise to lateral roots and secondary meristems, i.e. cambium and cork-cambium	gives rise to *lateral roots* only.
4 Cambium	appears later as a secondary meristem	altogether absent.

Transition from the R[illegible] [illegible] continuous from [illegible] ments in the two cases. In the stem they are collateral, but [illegible] root they are radial. How and where has this transition taken place? If we trace the vascular bundles from the root to the stem we find that each xylem and phloem bundle divides radially into two. Phloem

bundles remain practically in the same position, but xylem bundles change position, and each rotates till it lies on the inner side of the adjacent phloem bundle. As the xylem bundles undergo this transition they twist round so that the centripetal (exarch) xylem in the root now becomes centrifugal (endarch) in the stem. This transition

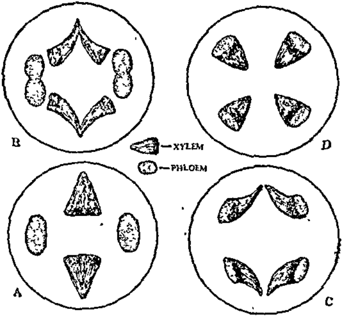


FIG. 62. Transitional stages from the root to the stem.

from the root to the stem is seen to take place in the region which is neither a typical root nor a typical stem, and that region is the hypocotyl. There are also other methods by which this transition takes place.

Origin of Lateral Roots (FIG. 63). Lateral roots originate from an inner layer; so they are said to be *endogenous*. The inner layer is the pericycle. The cells of the pericycle lying against the protoxylem begin

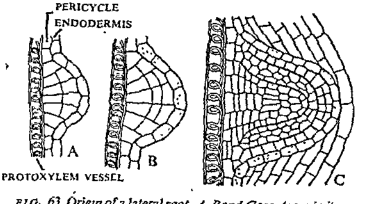


FIG. 63. Origin of a lateral root. *A*, *B* and *C* are stages in its formation from the pericycle.

to divide tangentially, and a few layers are thus cut off. They push the endodermis outwards and tend to grow through the cortex. At this stage the three regions of the root apex, namely, dermatogen (or calyptrogen), periblem and plerome, become well marked out. The endodermis and some of the cells of the cortex form a part of the root-cap, but as the root passes through the soil this portion soon wears off, and the root-cap is renewed by the calyptrogen.

Chapter 6 ANATOMY OF LEAVES

I. DORSIVENTRAL LEAF (FIG. 64)

A section cut through the blade of such a leaf (see p. 43) at a right angle to one of the veins reveals the following internal structure.

1. **Upper Epidermis.** A single layer of cells with a thick cuticle which checks excessive evaporation of water from the surface. It does not contain chloroplasts or stomata.

2. **Lower Epidermis.** Similarly a single layer but with a thin cuticle. It is, however, interspersed with numerous stomata, the two guard cells

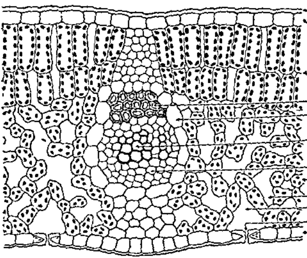


FIG. 64. A dorsiventral leaf in section.

of which contain some chloroplasts; none are present in the epidermal cells. Internal to each stoma a large cavity, known as the respi-

ratory cavity, may be seen. The lower epidermis of the leaf is meant for the exchange of gases (oxygen and carbon dioxide) between the atmosphere and the plant body. Excess of water contained in the plant body also evaporates mainly through the lower epidermis.

3. **Mesophyll.** The ground tissue lying between the two epidermal layers is known as the mesophyll. It is differentiated into (1) **palisade parenchyma** and (2) **spongy parenchyma.**

(1) **Palisade parenchyma** consists of usually one to two or three layers of elongated, more or less cylindrical cells, closely packed with their long axes at right angles to the epidermis, leaving only narrow intercellular spaces here and there. They contain numerous chloroplasts which are arranged alongside the cell-walls. The function of palisade parenchyma as a whole is to manufacture sugar and starch in the presence of sunlight, i.e. during the day.

(2) **Spongy parenchyma** consists of oval, rounded, or more commonly irregular cells, loosely arranged towards the lower epidermis, enclosing numerous large intercellular spaces and air-cavities. They, however, fit closely around the vein or the vascular bundle. The cells contain a few chloroplasts, and manufacture sugar and starch to some extent only. Spongy cells help diffusion of gases through the empty spaces left between them.

4. **Vascular Bundles.** Vascular bundles (or veins) ramify through the leaf-blade for facility of distribution of water and mineral salts among the green cells, and collection of prepared food material from these cells. As they pass from the base of the leaf-blade towards its apex or margin they get reduced in size as well as in the number of their elements. Each vascular bundle (vein) consists of xylem always lying towards the upper epidermis and phloem always towards the lower. Xylem consists of various kinds of vessels (particularly annular and spiral), tracheids, wood fibres and wood parenchyma. Towards the apex of the vein xylem is represented by only a few narrow annular and spiral tracheids, or even by a single spiral tracheid; other elements disappear. Xylem conducts and distributes the water and the raw food material to different parts of the leaf-blade. **Phloem** consists of some narrow sieve-tubes, companion cells and phloem parenchyma. Towards the apex a few undeveloped sieve-tubes with companion cells may be seen. Phloem carries the prepared food material from the leaf-blade to the growing and storage regions.

Surrounding each vascular bundle there is a compact layer of thin-walled parenchymatous cells, containing a few to many chloroplasts or none at all; this layer is known as the **border parenchyma or bundle sheath.** The cells of this layer are elongated running parallel with the course of the vascular bundle and extending right up to the end of it. The bundle sheath may also extend radially towards the upper or the lower epidermis or towards both as *bundle sheath extensions.*

The border parenchyma takes part in conduction between the vein and the mesophyll; it often photosynthesizes actively; and it may act as a starch sheath.

The distribution of **sclerenchyma** is very irregular in leaves; sometimes it forms patches here and there in the mesophyll; at other times it forms a continuous zone connecting two or more vascular bundles, or it occurs as a patch flanking a vascular bundle, or it extends from the epidermis, upper or lower, to one or more bundles. Frequently, however, it occurs as one or two patches lying associated with xylem (FIG. 64) or phloem or both. Sometimes sclerenchyma occurs as a more or less complete sheath (**sclerenchymatous sheath**) surrounding a vascular bundle (vein). In any case sclerenchyma gradually disappears towards the end of the vein.

II. ISOBILATERAL LEAVES (FIGS 65-66)

A section cut at a right angle to one or more veins of any of such leaves (see p. 43) reveals the following internal structure:

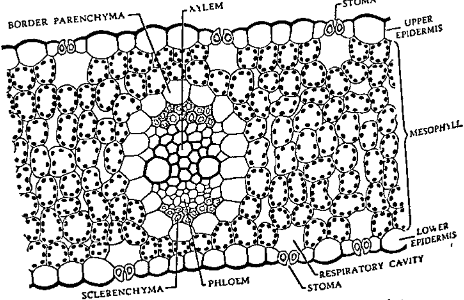


FIG. 65. An isobilateral leaf (a lily leaf) in section.

The structure is more or less uniform from one surface to the other. The epidermis on either side contains more or less an equal number of stomata, and is also somewhat uniformly thickened and cutinized. The mesophyll is not normally differentiated into palisade and spongy parenchyma, but mostly consists of spongy cells only, in which the chloroplasts are evenly distributed. Instead of spongy cells the mesophyll may consist of palisade cells only, as in many shade

plants. In some cases the mesophyll is seen to be differentiated into spongy parenchyma in the centre and palisade parenchyma on either

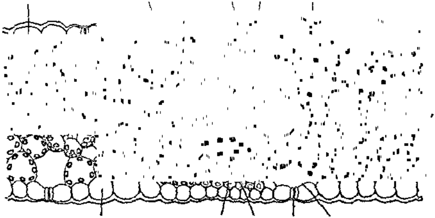


FIG. 66. An isobilateral leaf (maize leaf) in section.

side. The vascular bundle, border parenchyma and sclerenchymatous sheath are much the same as in a dorsiventral leaf.

Chapter 7 SECONDARY GROWTH IN THICKNESS

(I) Dicotyledonous Stem

In perennial dicotyledons (shrubs and trees) after the primary tissues are fully formed, the cambium becomes active and begins to cut off new (secondary) tissues in the stelar region. Sooner or later another strip of meristem, the cork-cambium, makes its appearance in the peripheral region and begins to form other secondary tissues, viz. cork, etc., in that region. All these secondary tissues are added on to the primary ones, and as a result the stem increases in thickness. *This increase in thickness, due to the addition of secondary tissues cut off by the cambium and the cork-cambium in the stelar and extra-stelar regions respectively, is spoken of as* secondary growth.

A. ACTIVITY OF THE CAMBIUM

Cambium Ring. It is seen that some of the medullary ray cells, mostly in a line with the fascicular cambium (i.e. the cambium of the vascular

bundle), become meristematic and form a strip of interfascicular cambium (i.e. the cambium in between two vascular bundles). This joins on to the fascicular cambium on either side and forms a complete ring known as the cambium ring.

Secondary Tissues. The cambium ring as a whole becomes actively meristematic and gives off new cells both externally and internally. Those cut off on the outer side are gradually modified into the elements of phloem; these constitute the **secondary phloem**. The secondary phloem consists of sieve-tubes, companion cells and phloem parenchyma and often also some bands or patches of bast fibres. Many of the textile fibres of commerce such as jute, hemp, flax, rhea (or ramie), etc., are the bast fibres of secondary phloem.

The new cells cut off by the cambium on its inner side are gradually modified into the various elements of xylem; these constitute the secondary xylem. The secondary xylem consists of scalariform and pitted vessels, tracheids, numerous wood fibres arranged mostly in radial rows, and some wood parenchyma. The cambium is always more active on the inner side than on the outer. Consequently xylem increases more rapidly in bulk than phloem, and soon forms a compact mass. As a matter of fact the secondary xylem forms the main bulk of the plant body after secondary growth. In consequence of continued formation of secondary xylem and the pressure exerted by it the cambium, the phloem and surrounding tissues are gradually pushed outwards, and for the same reason some of the primary tissues get crushed. The primary xylem, however, remains more or les

ch

and the secondary phloem; these are the **secondary medullary rays**. They are one, two or a few layers in thickness, and one to many layers in height.

Annual Rings (FIGS. 67-8). In regions where climatic variations are of pronounced nature the activity of the cambium is not uniform throughout the year. In spring or during the active vegetative season with greater production and activity of foliage leaves, the need to transport sap is acute, and hence at this time of the year the cambium is more active and forms a

cavities (large pitted vessels).

however, when there is less d

bium is less active and forms elements of narrower dimensions

kinds of wood appear together, in a transverse section of the stem, as a concentric ring known as the **annual ring or growth ring** (FIG. 68),

and successive annual rings are formed year after year by the activity of the cambium. *There is a sharp contrast between the late autumn* wood and the early spring wood, and this makes the successive rings distinct even to the naked eye. Annual rings are readily seen with the naked eye in the trunk of a tree which has been cut down transversely (FIG. 67). Each annual ring corresponds to one year's growth, and by counting the total number of annual rings the age of the plant can be approximately determined, as in pine and many timber trees.

FIG. 76

FIG. 67. Cut surface of stem showing annual rings.

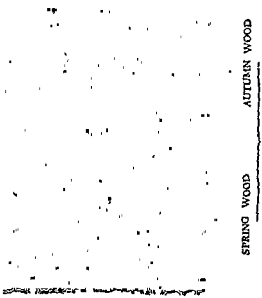


FIG. 68. An annual ring in section (magnified).

FIG. 68

The number of annual rings may, however, vary in many plants. In some trees large spring vessels are arranged more or less in a ring; the wood then is said to be **ring-porous.** In others they are distributed more or less *uniformly throughout* the whole spring wood; the wood then is said to be **diffuse-porous.** Annual rings of successive years may vary greatly in width. Wide rings are formed under favourable conditions of growth of the tree, and narrow ones are formed when conditions are unfavourable.

Heart-wood and Sap-wood. In old trees the *central region of the* secondary wood is filled up with tannin and other substances which make it hard and durable. This region is known as the **heart-wood or duramen.** It looks black, owing to the presence of tannins, oils, gums, resins, etc., in it. The vessels often become plugged with *tyloses* (see FIG. 76), which are balloon-like ingrowths, developing from the adjoining parenchyma, through the pits. The function of the heart-wood is no longer conduction of water, but simply to give mechanical support to the stem. The outer region of the secondary wood which is

of lighter colour is known as the sap-wood or **alburnum**, and this alone is used for conduction of water and salt solutions from the root to the leaf.

B. ORIGIN AND ACTIVITY OF THE CORK-CAMBIUM

The formation of new tissues by the cambium exerts a considerable pressure on the peripheral tissues of the stem. The epidermis becomes considerably stretched and gets ruptured here and there, often breaking down altogether. Sclerenchyma and collenchyma become much

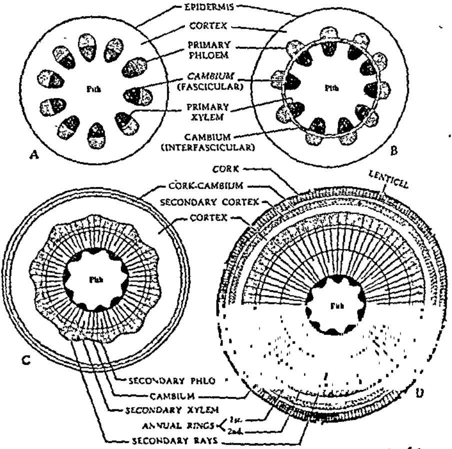


FIG. 69. Diagrams showing stages in the secondary growth of a dicotyledonous stem up to two years.

flattened tangentially. Cortex is also similarly affected but it persists [illegible] peripheral protective tissues, particularly the epidermis, a se[illegible] secondary meristem, called the cork-cambium or phellogen (*phellos*, cork: *gen*, producing) arises in that region to give rise to new

(secondary) tissues for better protection of the stem at the secondary stage. The cork-cambium commonly originates in the outer layer of collenchyma. It may also arise in the epidermis itself, or in the deeper layers of the cortex. In the formation of the cork-cambium the outer layer of collenchyma becomes meristematic; it divides and forms a thin strip of cork-cambium consisting of a few rows of narrow, thin-walled and roughly rectangular cells; these calls are living and active. The cork-cambium takes on meristematic activity and begins to divide and give off new cells on both sides, forming the secondary cortex on the inner side and the cork on the outer side.

Secondary Cortex. Those that are cut off on the inner side are parenchymatous in nature. These constitute the secondary cortex or phelloderm. The cells of the secondary cortex generally contain chloroplasts and carry on photosynthesis. Sometimes they are thick-walled, but made up of cellulose and provided with pits. The cells of the secondary cortex are arranged in a few rows, and are added on to the primary cortex.

Cork. The new cells cut off by the cork-cambium on its outer side are roughly rectangular in shape and soon become suberized. They form the cork or phellem of the plant. The cork tissue of cork oak (*Quercus suber*), a Mediterranean plant, is of considerable thickness, and is the source of bottle cork. When this is removed from the tree a fresh strip of cork is produced by the underlying cork-cambium. Cork cells are dead, suberized and thick-walled. They are arranged in a few radial rows, without leaving intercellular spaces between them, and are usually brownish in colour. Being suberized the cork is impervious to water, and it thus cuts off the outer tissues from the supply of water and food material. Consequently, they soon die off and act as the bark of the plant. Both cork and bark are protective tissues (see pp. 222-3).

All the new tissues formed at the peripheral region, viz. the cork or phellem, the cork-cambium or phellogen and the secondary cortex or phelloderm, are together known as the periderm.

Bark. All the dead tissues lying outside the active cork-cambium constitute the bark of the plant. It, therefore, includes the epidermis, lenticels and cork, and sometimes also hypodermis and a portion of the cortex, depending on the position of the cork-cambium, that is, the deeper the origin of the cork-cambium the thicker is the bark.

When the cork-cambium appears in the form of a complete ring the bark that is formed comes away in a sheet; such a bark is known as the ring-bark, as in *Betula* (B. BHURJJA-PATRA); and when it appears in strips the resulting bark comes away in the form of scales; such a bark is, therefore, known as the scale-bark, as in guava. The function of the bark is protection (see p. 223).

producing compact rows of cork cells, usually forms oval, spherical or irregular cells which are very loosely arranged, leaving a lot of intercellular spaces between them. The lenticel commonly develops below a stoma, and as its cells increase in number and size the epidermis gets ruptured. Communication is thus established between the atmosphere and the internal tissues of the plant. The gases can then easily pass in and out through the lenticel. To facilitate the diffusion of gases empty spaces are left between the different rows, upper and lower, of the cork and the cork-cambium. The lenticel may be closed in winter by the formation of cork; this, however, gets ruptured as the new active season begins.

Tissues in Primary Structure	Meristematic Tissues	Tissues in Secondary Structure
		1 Bark
Epidermis		(a) Epidermis
		(b) Lenticels
		(c) Cork
Collenchyma →	Cork-cambium →	2 Cork-cambium
		3 Secondary cortex
		4 Collenchyma
Primary cortex		5 Primary cortex
Endodermis		6 Endodermis
Pericycle		7 Pericycle (sclerenchyma)
Medullary rays →	Interfascicular cambium	
Primary phloem		(gets crushed)
		8 Secondary phloem
		9 Cambium ring
Cambium →	Cambium ring →	10 Sec. wood (annual rings)
		(a) Spring wood
		(b) Autumn wood
		11 Sec. medullary rays
Primary wood		12 Primary wood
Pith		13 Pith

(II) Dicotyledonous Root

As in the stem, the secondary growth in thickness of the root is due to the addition of new tissues cut off by the cambium and the cork-cambium in the interior as well as in the peripheral region. In the root the secondary growth commences a few centimetres behind the apex.

A. ORIGIN AND ACTIVITY OF THE CAMBIUM

The conjunctive tissue just flanking the phloem on its inner side becomes meristematic and by dividing gives rise to a strip of cam-

bium. It is evident that there are as many strips of cambium as there are phloem bundles. The cells of the conjunctive tissue lying in between xylem and phloem bundles also become meristematic so that the strips of cambium are seen to extend outwards between phloem and xylem. Then the portion of the pericycle abutting on the protoxylem becomes meristematic; it divides and forms a strip of cambium there, joining with the earlier-formed cambium strips on either side of xylem. Thus a continuous wavy band of cambium is formed, extending over the xylem and down the phloem (FIG. 72). The secondary growth then commences with the activity of this cambium band. The portion of the cambium adjoining the inner phloem becomes active first. It begins to cut off new cells on both sides, but more profusely on the inside. As a result of this increased formation of new cells on the inner side the cambium and the phloem are gradually pushed outwards. The wavy band of cambium soon becomes circular or ring-like, and thus a cambium ring is formed (FIG. 73). The whole of the cambium ring then becomes actively meristematic, and behaves in the same way as in the stem, giving rise to secondary xylem on the inside and secondary phloem on the outside.

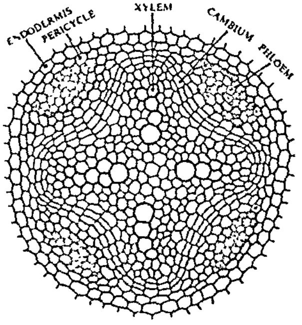


FIG. 72. Secondary growth of dicotyledonous root (early stage).

underground it is not subjected to variations of aerial conditions consequently annular rings, which are so characteristic of wood stems, are rarely formed in the root Even when the root has increased considerably in thickness the primary xylem bundles still remain in

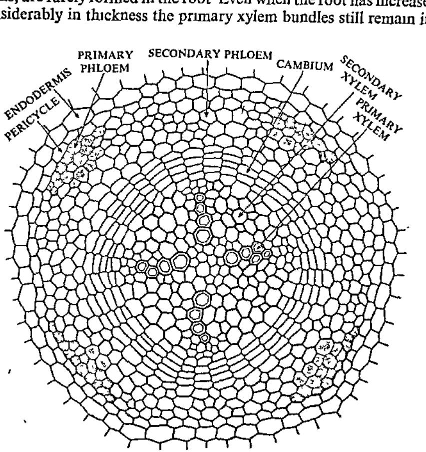


FIG. 73. Secondary growth of dicotyledonous root (later stage).

tact and can be recognized under the microscope in several cases. Against the protoxylem the cambium forms distinct and widening radial bands of parenchyma, which constitute the primary medullary rays. These extend up to the secondary phloem. Other smaller and thinner medullary rays are also formed later by the cambium. Medullary rays are larger and more prominent in the root than in the stem.

Secondary Phloem. The new elements cut off by the cambium on the outer side become gradually modified into the elements of phloem, and all these together constitute the secondary phloem. It consists of sieve-tubes with companion cells and abundant parenchyma, but less bast fibres (except in special cases). The secondary phloem is much thinner than the secondary xylem. The primary phloem soon gets crushed.

B. ORIGIN AND ACTIVITY OF THE CORK-CAMBIUM

When the secondary growth has advanced to some extent the single-layered pericycle as a whole becomes meristematic and divides into a few rows of thin-walled, roughly rectangular cells; these constitute the cork-cambium or phellogen. The cork cambium may also arise, in some cases, in the phloem. As in the stem, it produces a few brownish

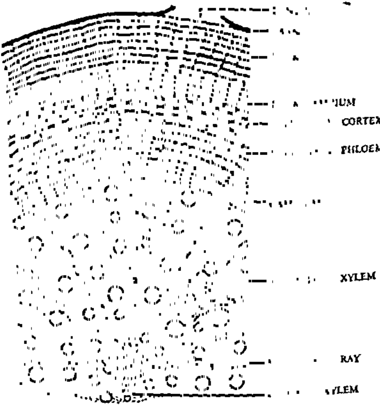


FIG. 74. A dicotyledonous root (a sector) in transection showing secondary growth in thickness.

layers of cork or phellem on the outside, and the secondary cortex or phelloderm on the inside. The secondary cortex of the root does not contain chloroplasts. The bark of the root is not extensive; it forms only a thin covering. The cortex, being thin-walled, is very much compressed and ultimately it gets disorganized, and sloughs off. Such is also the fate of the endodermis. Epiblema dies out earlier. Here and there lenticels may be developed, as in the stem.

Functions of Cork and Bark. Cork and bark are the protective tissues of plants. They are meant to check evaporation of water, to guard the plant body against variation of external temperature, and to protect it against the attack of parasitic fungi and insects.

(1) Cork. Sooner or later, in shrubs and trees, the epidermis is reinforced or sometimes replaced by the cork which then takes on the functions of the former, being essentially a protective tissue. The cork is always much thicker than the epidermis, and as such, it can afford greater protection than the epidermis. The renewal of the cork by the underlying cork-cambium is a decided advantage in this respect. All the cork cells are suberized, and thus the cork acts as a waterproof covering to the stem. Loss of water by evaporation is, therefore, prevented or greatly minimized. The cork tissue also protects the plant against the attack of parasitic fungi and insects. Cork cells, being dead and empty containing air only, are bad conductors of heat. This being so, sudden variation of outside temperature does not affect the internal tissues of the plant. Cork is also made use of by the plant for the healing of wounds.

(2) Bark. Since bark is a mass of dead tissues lying in the peripheral region of the plant body as a hard dry covering, its function is protection. It protects the inner tissues against the attack of fungi and insects, against loss of water by evaporation, and against the variation of external temperature. In many plants the bark sloughs off, and then all these functions are performed by the cork part only.

Protective Tissues. It is to be noted that there are three tissues in plants, namely, (1) the epidermis, (2) the cork, and (3) the bark, which develop for the specific purpose of protection. At an early stage of the plant the epidermis alone affords the necessary protection (see p. 185), but in shrubs and trees at a later stage the epidermis becomes reinforced or even replaced by the cork and the bark for the same purpose.

Chapter 8 · ANOMALOUS SECONDARY GROWTH IN THICKNESS

(1) Dicotyledonous Stem

A number of dicotyledons show anomaly in their growth in thick-
[illegible] ick-
[illegible] ular
[illegible] no-
[illegible] plants (1) In some plants, as in *Bignonia*, *Thunbergia*, *Bauhinia*, *Aristolochia*, etc., the cambium is normal in position but its behaviour is irregular giving

ed secondarily, giving rise to xylem and phloem in an irregular manner; (3) in still other plants, as in some species of *Piper*, the cambium is abnormal in position giving rise to abnormal xylem and phloem.

Secondary Growth in *Amarantus* Stem. In the young stem the primary vascular bundles remain scattered. The cambium in them is either feebly developed and functionless or is absent. The region of pericycle outside the scattered primary bundles soon becomes meristematic and forms into a 5- or 6-layered cambium. It begins to cut off secondary xylem and secondary phloem in the form of bundles towards the inside only. Sometimes the cambium is also seen to produce interxylary phloem. In addition the cambium also cuts off some amount of parenchyma towards the inside, in which the bundles of secondary origin lie embedded. The cambium instead of forming secondary phloem on the outer ~~side produces a~~ little parenchyma there or sometimes none at all. As the secondary bundles increase in number they form a con
lying in between the vas
compact structure so forn
interrupted by thin strips of parenchyma. There is very little or no formation of periderm in *Amarantus*.

(II) Monocotyledonous Stem

Secondary growth in monocotyledons is rather rare. It is commonly seen in woody *Liliaceae* such as *Dracaena, Yucca, Aloe*, etc., and in *Agave* of *Amaryllidaceae*. Exceptionally a large amount of secondary growth in thickness is seen in some species of *Dracaena*. One plant of *Dracaena draco* in the Canary Isles measured 14 metres in girth at the base and was 6,000 years old when it was destroyed by a storm in 1868. It may be noted that the stout stems of palms are not the result of secondary growth but are the result of protracted primary growth by a primary thickening meristem occurring beneath the apical meristem. Although often very stout no cambium is formed in them and, therefore, there is no secondary growth in such plants.

Secondary Growth in *Dracaena* Stem (FIG. 75). The primary structure is a typically monocotyledonous one with numerous closed and collateral vascular bundles lying scattered in the ground tissue. Secondary growth in it begins with the formation of a secondary meristematic tissue—the cambium—in the parenchyma outside the primary bundles. This layer divides tangentially and forms a band of cambium, a few layers in thickness. The cambium thus formed is

more active on the inner side. It begins to cut off new cells towards the inside, which soon become differentiated into distinct vascular bundles (secondary) and thick-walled, often lignified, parenchyma (secondary). On the outer side the cambium only produces some amount of thin-walled parenchyma which may contain some crystals. While the primary bundles remain scattered the secondary ones are somewhat radially seriated and so also the surrounding secondary parenchyma which is often thick-walled and lignified. The vascular

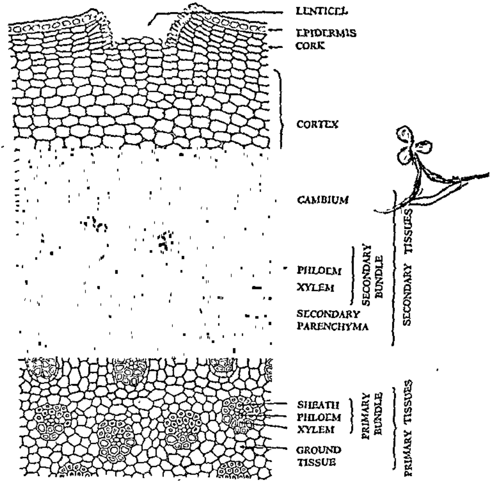


FIG. 75. Secondary growth of monocotyledonous stem (*Dracaena*).

bundles are oval in transection, and concentric with phloem in the centre surrounded by xylem (amphivasal). In some species of *Dracaena* the vascular bundles are, however, collateral. Phloem consists of short sieve-tubes, companion cells and phloem parenchyma; while xylem consists of long tracheids with a small amount of thick-walled (lignified) wood parenchyma. After the secondary growth has proceeded to some extent the peripheral parenchyma becomes meris-

tematic and begins to divide tangentially and so also the cells derived from them until a few linear layers are formed. The cells then become suberized and differentiated into cork. Some deeper-lying parenchyma again begins to divide and the new layers formed from it again give rise to a strip of cork in the same way. Thus the cork in *Dracaena* appears in seriated bands without the formation of cork-cambium (phellogen) and is known as **storied cork.**

Chapter 9 HEALING OF WOUNDS AND FALL OF LEAVES

Healing of Wounds. *In cases of simpler wounds,* the wounded cells die and dry up, while outer walls or cells of the underlying uninjured layers become impregnated with protective substances.

In cases of larger wounds, the outermost uninjured layer of living *parenchymatous tissue forms a meristem (phellogen) which produces* one or more layers of cork—the **wound cork**; the cork then protects the wounded surface.

Frequently in woody plants the uninjured cells adjoining *the wound do not directly produce the cork tissue, but give rise to a* succulent mass of parenchymatous cells, called the **callus.** This callus fills up and covers the wound, and not infrequently it overgrows it. This explains the origin of knots in some trees. If the cambium is injured the cells of the callus often form a *fresh strip of cambium* which becomes connected with the original cambium.

Sometimes, instead of any fresh layer being formed, the tracheae or wood vessels develop tracheal plugs, called **tyloses** (FIG. 76), which are balloon-like ingrowths developing from the adjoining parenchyma through pits. Tyloses plug the lumen of the vessels, while other elements simply dry up. Latex, if present, coagulates. In this way loss of water is prevented from the exposed surface.

Fall of Leaves. In deciduous trees and shrubs the leaf falls in the dry season, when the absorption of water by roots is minimized and the evaporation of water from the surfaces of leaves is enhanced. Both conditions prevail in winter or in a prolonged dry summer and, therefore, the leaf is seen to fall at that time. The immediate structural cause of the leaf-fall is the formation of a layer of cork across the base of the petiole and the development of a well-defined *separation layer*, called the **abscission layer,** just external to the cork. The living parenchymatous cells lying across the base of the petiole, and also

those of the vascular bundles, become meristematic and form a layer of cork, or these living cells become suberized directly, forming the cork layer without any division. In either case this cork is later reinforced by a fresh strip of cork formed by the underlying cork-cambium. In some cases the cork-cambium directly produces a few layers of cork at the base of the petiole. The cork being suberized and the vessels getting constricted owing to the lateral pressure of the cork, the leaf is cut off from the supply of water; it dries up and dies. The separation layer, or the absciss layer, lying just external to the cork, turns yellowish and gets disorganized. Cellulose of this layer becomes converted into pectin which dissolves, and thus the cells become separated from one another. The leaf then remains supported by the vessels only, and it breaks off mechanically at the absciss layer, either under its own weight or when disturbed by the wind. The vessels are clogged with gum and tyloses, and the exposed surface is covered with cork. Thus exudation of sap is prevented. When the leaf falls, a scar is left on the stem; this is called the **leaf-scar**.

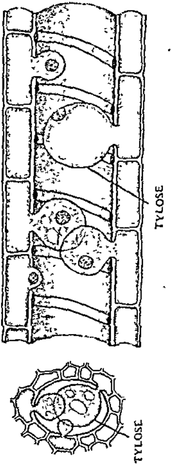


FIG. 76. Vessel with tyloses.

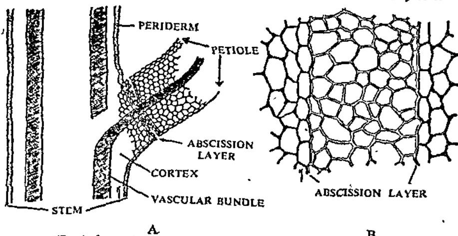


FIG. 77. *A*, formation of abscission layer at the base of the leaf; *B*, a portion of the abscission layer in surface view sometime before leaf-fall.

PART III *Physiology*

Chapter 1 GENERAL CONSIDERATIONS

A Short History. Experimental physiology actually began from the time of Stephens Hales (1677-1761), curate of Teddington in Middlesex. He was the first to devise experimental methods with his knowledge of physics and statistics to find out the movement of sap through the plant body, rate of transpiration current, suction due to transpiration, loss of weight due to transpiration, root pressure and capillarity as factors in the ascent of sap. Hales was the first to show

His *Vegetable Staticks* published in 1727 is a famous work.

America. Ingenhousz (1730-99), a physician educated in Holland, who later migrated to London in 1765, was interested from the medical point of view in the composition of the air. Priestley's work attracted his notice. He proved by an ingenious experiment (mouse and twig) in 1779 that green plants exposed to light for a few hours absorb carbon dioxide (bad air) unfit for respiration and exhale oxygen and thus purify the air. He further proved that at night plants vitiate the air by their respiration, as do animals.

Photosynthesis. Early work on photosynthesis carried out by De Saussure (1804),

Saussure, 1804; Sachs, 1882); the two volumes are equal (Boussingault, 1864); sunlight is essential for the process; chlorophyll absorbs light, which induces chemical changes in carbon dioxide (Timiriazeff, 1872); plastids cannot photosynthesize without chlorophyll; water is also fixed in the process; starch is the first visible product (Sachs, 1862 and 1864); CO_2 is the source of all organic compounds in plants. Baeyer in 1870 formulated the 'formaldehyde theory' for the production of carbohydrates in photosynthesis (lately discarded). Willstatter and Stoll in 1918 modified Baeyer's view and suggested that sugar is formed in several stages (at least six). Warburg in 1919 working on *Chlorella* agreed with Willstatter and Stoll but introduced 'light reaction' and 'dark reaction' (which he called Blackman reaction) in the intermediate processes of photosynthesis. Since then much spadework has been done and only recently have the main facts regarding photosynthesis been elucidated (see text).

Nitrogen Assimilation. In 1840 Liebig, an agricultural chemist, formed the idea that plants obtain their nitrogen from the air and that ammonia is the source. Boussingault (1802-87) carried out a long series of experiments from 1837 to 1852 (and later) and came to the conclusion that plants do not utilize free nitrogen of the air and that nitrate of the soil is the principal source. He reported, however, in 1838 that certain plants like lupin, *Trifolium*, etc., grown in calcined soil to which only distilled water was added, showed a gain in weight in nitrogen; while wheat grown under the same condition showed no such gain. Boussingault's views were corroborated by Lawes and Gilbert in 1861 and later by Hellriegel, Russell and others. The importance of nitrogen in plant growth was determined by Sachs and Knopp in 1860 and 1865 by their water culture experiments. Hellriegel and Wilfarth in 1887 first discovered the fixation of nitrogen by symbiotic bacteria in the root-nodules of leguminous plants. The formation of ammonia from plant proteins in the soil by the action of certain soil organisms (especially *Bacillus mycoides* and also several fungi) was made known by the work of Marchal in 1893 and later by others. Winogradsky's (1856-1934) elucidation of nitrification in 1890-91 was most valuable. He established the fact that one type of oval bacteria which he named *Nitrosomonas*, is responsible for oxidation of ammonia to nitrite, and a second type of rod-shaped bacteria which he named *Nitrobacter*, for further oxidation of nitrite to nitrate. Jensen in 1898 showed that denitrification is due to the action of a group of putrifying bacteria called *Pseudomonas*.

The Colloidal System. Protoplasm exists in a colloidal condition (see p. 134) and various physiological processes are attributable to the colloidal nature of the cell contents. Most soils also contain materials in colloidal state. As a matter of fact the colloids play an im- [illegible]

[illegible] could be divided into two classes—crystalloids and colloids according to the rates at which their solutions passed through a parchment membrane (dialyser). Substances such as salts, sugar, urea, etc., which diffuse readily, were termed *crystalloids* because of the fact that they generally exist in crystalline form; on the other hand substances such as gelatine, albumen, gum, silicic acid, starch, etc., which diffuse at a very slow rate, were termed *colloids* (meaning glue-like). This distinction, as was later realized by Graham and others, is not rigid since many crystalline substances can be obtained in colloidal solution, e.g. sodium chloride in benzene. Further X-ray studies have shown that particles in colloidal systems are often truly crystalline in character. Consequently instead of the term colloid or colloidal substance it is the practice to refer to the colloidal state or to a colloidal system.

General Properties of Colloidal System. In a colloidal solution the particles are either very large molecules or aggregates of a large number (even thousands) of molecules, still not visible under the

microscope. If, however, the colloidal particles grow further in size, they become visible *under the microscope*. A colloidal *solution* is essentially a *two-phase system*: a disperse phase or discontinuous phase consisting of the discrete particles, and a dispersion medium or continuous phase consisting of the medium (solid, liquid or gaseous) in which the particles are distributed. When the dispersion medium is water the colloidal solution is commonly called hydrosol. In a *true solution*, however, the *particles* are of molecular size and there is no true surface of separation between the disperse phase and the dispersion medium. Colloidal solutions consisting of large

...nsion in the dispersion

... do not play any signi-

...uspensoids are, however, common

... Emulsions can be stabilized by adding a third substance called *emulsifier*, e g. casein in milk stabilizing fat globules. When a colloidal solution resembles a solid or a jelly-like substance, *it is* called a gel; gelatine, agar agar, pectin, silicic acid, etc., easily form gels; common fruit jelly is a familiar example of gel. When *the* colloidal solution looks like a liquid, it is called a sol. A gel and a sol may be reversible, and protoplasm is a reversible colloid (*see* p. 134). Colloidal solutions in water are termed hydrosols. *Similarly* there may be alcosols, *benzosols, etc.*

Colloidal solutions with a liquid as dispersion medium fall into

... are hydrophobic and hydrophilic. Gelatine, agar agar, gum, silicic acid, various albumens, starch, soap and many dyes, etc., which directly pass into colloidal solutions when brought in contact with

... y are also called

... , *metal sulphides,*

... on the other hand which *do* not readily yield colloidal solutions when brought in contact with water, are examples of hydrophobic colloids; they are also called irreversible colloids.

The characteristic property of the disperse system *is attributable* to the enormous surface area of the disperse phase. A *solid block* reduced to colloidal particles enormously increases *the exposed surface* area. One of the most important results of the *large surface area* is the adsorption of ions and other materials by the *particles. This* adsorption may lead to the formation of electric *charges* on the particles which prevent them from collecting into *larger aggregates.* The surface of the colloidal particles is the seat of *chemical energy* and various chemical reactions take place here. The *adsorption* is

somewhat selective, and is an important factor in plant physiology, particularly with reference to the cytoplasmic membrane (ectoplasm).

Optical Properties. The presence of colloidal particles although not detectable under a microscope can be made evident by optical means. Thus if an intense beam of light be passed through a colloidal solution, the particles in it scatter the light and the beam is rendered visible indicating the presence of particles which are larger than molecules but too small to be separated by filtration. The phenomenon of scattering the light by the particles is known as the Tyndall effect after the name of its discoverer. The Tyndall effect has been better demonstrated by the ultramicroscope invented by Siedentopf and Zsigmondy. The presence of individual particles is made evident by this instrument as flashes of scattered light. It does not, however, reveal the shape, colour, or relative size of the particles.

Brownian Movement. Careful ultramicroscopic examination of a colloidal solution reveals that the particles of the disperse phase are in constant, rapid, zigzag motion called the Brownian movement after the name of its discoverer Sir Robert Brown. Particles within the range of microscopic visibility also show this phenomenon. Brownian movement counteracts the force of gravity acting on the colloidal particles and is thus responsible to a certain extent for the stability of the colloidal solutions. Brown first noted this movement while examining pollen grains suspended in water. Brownian movement is caused by molecular impacts, i.e. bombardment by the molecules of the dispersion medium on the colloidal particles on any one side of them at any given moment.

Electric Properties. An important property of colloidal solutions is that their particles carry an electric charge, either positive or negative, and, therefore, move towards one or the other electrode when a solution is placed in an electric field. This migration of colloidal particles under the influence of electric field is called *cataphoresis*.

Flocculation. Flocculation of many colloidal systems, e.g. white of egg, is the change into an irreversible gel condition brought about by various means such as increased frequency of collisions of particles resulting in the formation of larger particles or masses, or by the application of heat or cold, or by the addition of a dehydrating agent such as alcohol. Flocculation is most commonly initiated by the introduction of electrolytes. An important property of many colloidal systems is their sensitivity to small quantities of electrolytes. The presence of a small quantity of ionizable substances causes the particles of many colloidal systems to coagulate so that a visible precipitate is readily formed. The term flocculation, or coagulation or precipitation is employed to designate such a condition. It may

be noted that very small quantities of an electrolyte may caus flocculation of a large volume of the solution.

Diffusion. This is the movement of molecules or ions of a solute o a *solvent*, be *it* a *liquid* or a *gas*, from the *region of its higher con*centration to that of its lower concentration. Diffusion continue until an equilibrium is reached. The molecules or ions are i continuous motion following straight pathways at different speed (according to their specific nature and the surrounding conditions deflected, however, only by collision. Molecules or ions enter plan cells and move from one to the other by following the simple lav of diffusion from the region of higher *concentration to that of lowe concentration*. So far as the diffusion of soil solution into the root hairs is concerned the process is not considered to be of primary importance Diffusion is, however, the basic phenomenon of osmosis and imbibition.

Imbibition. Imbibition is the phenomenon of soaking up water by *certain materials*, particularly in dry or semi-dry condition. *Fibres*, pieces of wood, some proteins, sponges, etc., are some such *materials*. [illegible]

two. Thus cotton fibres imbibe water, while rubber does not. In this process the constituent particles of a particular substance take up water by *surface attraction* and increase in volume. For this reason [illegible]

body. As a result of imbibitional pressure the seed-coat of a germinating seed bursts. Germinating seeds kept in a closed vessel often burst it with tremendous pressure. Imbibition is believed to be an important force concerned in the ascent of sap (see p. 271). Imbibition also plays an important part (together with osmosis, as explained at p. 256) in the intake of soil-water by the root-hairs. *In an imbibing* system it is the rule that the water always moves with some force from a saturated region to a drier region.

Osmosis. It has been observed that there are certain membranes which when used to separate a solvent (water, for example, which is [illegible] minute quantity of the latter can cross through. On account [illegible] property of selective transmission such membranes are said to be semi-permeable or differentially permeable. Parchment paper, fish- or animal-bladder and egg-membranes are some such membranes. So

the stem has gone up. This rise is due to the accumulation of water in the funn as a result of more rapid flow of the water into it by osmosis (endosmosis) throug the membrane. This rise of water is seen to continue until the level has go sufficiently high up to exert a hydrostatic pressure on the membrane which the stops further net transfer of water by osmosis. This value of the hydrostat pressure is equal to the osmotic pressure of the solution. At the same tim a small quantity of salt also passes out through the membrane.

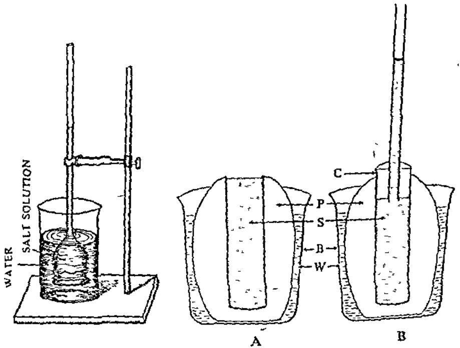


FIG. 1 FIG. 2

Experiments on Osmosis. FIG. 1. Physical process of osmosis. FIG. 2. Physiological process of osmosis. *A*, experiment with potato tuber; *B*, the same with potato osmometer. *C*, cork; *P*, potato tuber; *S*, sugar solution; *B*, beaker; *W*, water.

Experiment 2. Physiological process of osmosis (FIG. 2A). (*a*) Take a large potato uber and size it into a bowl in the fc lice off the bottom to make it flat. calpel or borer into a deep hollow ... 'lace the potato bowl in a small beaker and pour some strong salt or sugar olution into it so as to cover more or less three-fourths of the cavity. Then pour

The presence of a small quantity of salt or sugar may also be detected in the vater of the beaker as a result of exosmosis.

(*b*) The experiment may be carried out in a modified form with a potato

beaker and fill it (the beaker) with water. Within a short time the salt or sugar solution is seen to rise in the glass tube, soon overflowing it. The actual rise is one to a few metres, depending on a number of factors.

Importance of Osmosis in Plant Life. (1) Root-hairs absorb water from the soil by the process of osmosis; at least this entry is controlled by osmosis. (2) From the root-hairs cell to cell osmosis takes place until the cortical cells of the root become saturated with water. Similar cell to cell osmosis takes place throughout the body of the plant. (3) The osmotic pressure generated in the root-cortex is responsible for forcing the water into the xylem vessels, and possibly upwards through them at least to some height. (4) The living cells surrounding xylem draw water from it by this process, and so do the mesophyll cells of the leaf at the upper end of xylem, prior to transpiration. (5) Osmosis makes the cells turgid. This turgid condition gives a certain amount of rigidity to the young soft parts of the plant body, and is also an essential condition of growth. Enlargement of meristematic cells at the root-apex and stem-apex is due initially to osmosis. (6) Various movements, turgor movements particularly, such as those exhibited by the leaflet of Indian telegraph plant (see FIG. 47), sensitive plant (see FIG. 53), sensitive wood-sorrel (see FIG. 52), sleep movement by most species of *Leguminosae*, opening and closing of stomata, bursting of many fruits and sporangia, etc., are largely due to osmotic phenomena. (7) By plasmolysis which is an osmotic phenomenon it is possible to determine the osmotic pressure of a cell (see experiment 3).

Turgidity. As a cell absorbs more and more water resulting in its accumulation in the vacuole, a certain pressure is exerted on the surrounding protoplasm and the cell-wall. As a consequence the protoplasm is forced outward against the cell-wall and the latter also becomes much stretched. The stretched cellulose wall being elastic tends to return to its original shape and thus in its turn exerts a pressure upon the fluid contents of the cell. *A cell thus charged with water with its wall in a state of tension is said to be turgid, and the condition is designated as* turgidity *or* turgor. It will be noted that in a cell in a turgid condition two pressures are involved: outward and inward. The outward pressure exerted on the cell-wall by the fluid contents of the cell is called the turgor pressure, and the inward pressure exerted on the cell-contents by the stretched cell-wall is called the wall pressure. Normally these two pressures counterbalance each other and a state of equilibrium is maintained between them. Three factors influence the turgidity of a living cell, viz. (1) formation of osmotically active substances inside the cell, (2) an adequate supply of water, and (3) a semi-permeable membrane.

Importance. Turgid condition is necessary for the transit of nutrient solution from cell to cell; this is so because of the difference in the

concentration of the cell-sap between one cell and the other. Turgidity is also necessary for growth; in fact, it is always the initial stage of growth. Rapid growth of certain organs of plants is principally due to turgidity, i.e. full expansion of the cells of those organs, and not to their rapid multiplication. Turgidity is also responsible for various movements of different organs of the plant. Thus movements of the guard cells of the stomata are due to changes in the turgidity of these cells, and similarly, the rising and the falling of the leaf and the leaflets of sensitive plant (see FIG. 53), Indian telegraph plant (see FIG. 47), etc., are brought about by alterations in the turgidity of the cells of the pulvinus. Turgidity of the cells of the root-cortex is responsible for forcing the water into the xylem vessels. Turgidity also gives a certain amount of rigidity to the plant, particularly to the growing regions and the soft leaves which easily wilt in strong sunlight, and also to other soft parts composed of only thin-walled parenchyma without any mechanical tissue.

Plasmolysis (FIG. 3). If a section of a plant organ or a *Hydrilla* leaf or a coloured petal or a *spirogyra* filament be immersed in a *hypertonic* solution[1] (say, 5-10% sucrose solution) and after a few minutes observed under the microscope, it will be seen that the cell as a whole contracts and more obviously the protoplasm together with the nucleus and the plastids gradually shrinks away from the cell-wall and forms a rounded or irregular mass in the centre; while the space between the cell-wall and the protoplasmic mass becomes filled with the sugar solution. It will be noted that while the cell-wall is freely permeable to the solution the protoplasmic membrane is selectively or differentially permeable to it. The reason for such shrinkage of the protoplasm is that the sugar solution being of greater osmotic value than the cell-sap, the cell loses water by outward osmosis. As the water moves out of the cell, the protoplasm and the cell-wall are no longer in a state of tension. Further loss of water evidently results in the shrinkage of the protoplasm. *This shrinkage of the protoplasm from the cell-wall under the action of some strong solution—stronger than that of the cell-sap—is known as* **plasmolysis.** Protoplasm in one type of cells commonly follows the same pattern of shrinkage on plasmolysis. If the sugar solution be replaced by pure water, soon after plasmolysis, the protoplasm is seen to return to its normal position and the vacuole reappears (deplasmolysis). Potassium nitrate solution (10%) is a very good reagent to bring about plasmolysis readily and is, therefore, useful for general class-work.

Plasmolysis is a vital phenomenon. It explains on the one hand the phenomenon of osmosis, and on the other it shows the perme-

[1] A solution is said to be *hypertonic*, *isotonic* or *hypotonic* when its osmotic [illegible] of the cell being examined.

ability of the cell-wall and semi-permeability of the outer layer of the protoplasm—the ectoplasm—to the entrance of certain substances. Plasmolysis also shows that the protoplasm can retain the osmotically active substances of the sap. This is evident from the fact that the plasmolysed protoplasm turns back to its original position when the sugar solution is replaced by pure water. The phenomenon of plasmolysis also indicates whether the cells are living or dead. When a tissue is killed by boiling in water or by dipping into absolute alcohol or strong formalin solution for a *few seconds*, the cells show no plasmolysis From plasmolysis it is also possible to determine the osmotic pressure of cells (see experiment 3).

Experiment 3. Determination of osmotic pressure of plant cells by plasmolytic method. Sucrose solutions are most commonly used for this purpose because the osmotic pressures of different *molar concentrations*[1] *of sucrose have* been worked out with considerable amount of accuracy. First, a series of sucrose solutions of different molar concentrations are prepared. Then sections of plant tissues or entire material *in particular cases (e.g. Hydrilla* leaf *or Spirogyra* filament) are immersed in the graded solutions—0.1 M to 1.0 M—for 10 to 15 minutes and observed under a microscope. It will be found that in one particular solution about 50% of *the cells have just plasmolysed.* This *incipient* plasmolysis indicates that the solution has the same osmotic pressure as that of the cell-sap, and is said to be *isotonic* with it. The isotonic solution having been found, it is now possible to *determine the osmotic pressure of the* cells. It is known that one molar solution of sucrose (according to Morse, 1914) is equivalent to 26.64 atmos-

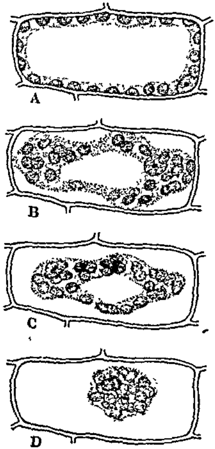


FIG. 3. *Plasmolysis in a cell of Vallisneria* leaf under the action of 10% potassium nitrate solution; *A*, a normal cell; *B-D*, stages in plasmolysis.

[1] A molar solution is prepared by dissolving one mol, i e. one gram molecular weight of a substance in 1 litre (1,000 c.c) *of distilled water at 20° C.* The molecular weight of sucrose ($C_{12}H_{22}O_{11}$) is $12\times12+22\times1+11\times16=342$. Thus 342 gms. of sucrose dissolved in 1 litre of water will give a normal molar solution or 1 M solution. This may be diluted to solutions of 0.1 M, 0.2 M, 0.3 M, etc. Molar solutions are commonly used in experiments on osmosis.

pheres of pressure at 20°C. If the isotonic solution in the above experiment be 0.5 M at 20°C, then the osmotic pressure of the cells immersed in that solution would be equal to 13.32 atm. It must be noted that the osmotic pressures of different groups of cells or those of the same group under different conditions vary considerably. Most of the values are, however, commonly within the range of 10-20 atm.

Chapter 2 SOILS

Since water and mineral salts are almost exclusively obtained from the soil for their utilization later in the plant body a knowledge of soil science in different aspects is an essential prerequisite to the study of plant physiology.

Soil Formation. Soils are formed by the disintegration and decomposition of rocks due to weathering (action of rain-water, running

long distances by agencies like rivers, glaciers, strong winds, etc.

in it. The soil has been graded into the following types according to the size of the particles:

Coarse particles	..	2 - .2 mm. form coarse sand
Smaller particles	..	.2 - .02 mm. form sand
Finer particles	..	.02 - .002 mm. form silt
Very fine particles	..	less than .002 mm. form clay

mined by the proportion of clay present in it. On this basis soils may be classified into the following types: (1) sandy soil containing more ... of sand;

The physical properties of soils are: porosity (30-50% of the pore space of the soil volume required for water and air is suitable for most crops), capillary action, hygroscopicity, weight, colour, temperature, quantity of humus present (see p. 242), etc. The important physical properties of the above types of soils are as follows. (1) Sandy soil is well aerated, being porous; but as it allows easy percolation of water through large pore spaces left between its particles it quickly dries up and often remains dry. Capillarity decreases in this soil; such a soil can retain only 25-31 parts of water by weight. The soil is always light. (2) Clay soil on the other hand is badly aerated and it easily becomes waterlogged. It has, however, a great capacity for retaining water (40 parts by weight), the particles being very fine. Drainage in this soil is difficult, while capillarity increases considerably. It is heavy and easily becomes compact, and cracks when dried up. A considerable amount of plant food is, however, available in this soil. (3) Loam is the best soil for vigorous plant growth and is most suitable for agricultural crops because all the important physical conditions are satisfied—porosity for better aeration and for percolation (downward movement) of excess water, and capillarity for upward movement of sub-soil water. It can retain 50 parts of water by weight. At the same time it is rich in organic food. The proportions of the above constituents of the soil can be approximately determined by stirring a small lump of soil in a beaker to which an excess of water has been added, and then pouring the contents into a measuring cylinder. When allowed to settle, it is seen that sand particles collect at the bottom, silt higher up, and clay on the top—these in distinct layers. The fine portion of the clay, however, remains suspended in water. Their proportions are then determined and percentages calculated. Humus mostly floats on water.

There are other kinds of soils also. Some of the common ones are: *calcareous soil* containing over 20% of calcium carbonate which is useful in neutralizing organic acids formed from humus; it is whitish in colour; the presence of calcium carbonate may be detected by adding strong hydrochloric acid to a small sample of soil when effervescence is noticed in it either with naked eyes or under a pocket lens; *laterite soil* containing a high percentage of iron and aluminium oxides; it is reddish, brownish or yellowish in colour; *peat soil* containing a high percentage (even up to 80% or 90%) of humus; it is dark in colour, porous and light; the floating garden of Kashmir is made of peat soil; it can absorb water to the extent of several times its own weight.

Physical Properties of Soils. The physical properties of soils largely depend on the size of the particles that such soils are composed of. Regarding their sizes the extremes are gravel and coarse sand at one end and clay at the other. Loam (see above) satisfies most of the

physical conditions favourable for plant growth. Besides, it contains a good amount of organic matter. The physical properties are:

Porosity. Porosity is a very important factor. Irregularity in the size of the soil particles and their arrangement always leave some space, called *pore space*, between them. however compact the soil may be. [illegible] room for water and [illegible] bigger pores, and capillary retention of water normally through smaller pores. Loam with more or less even distribution of finer and coarser particles is regarded as the best in respect of the above conditions. A good soil contains 30–50% of pore space of the soil volume.

Soil Water. Ordinarily two-thirds of the pore space occupied by water and one-third occupied by air are found to be suitable for normal growth of most crop plants. An excess of water in the soil [illegible] The water loosely held by the small soil particles by capillary force, with mineral salts dissolved in it, is the water absorbed by the root-hairs (see p. 255). So the *water-holding capacity* of the soil is of primary importance, and it mainly depends on the fineness of the soil particles. Ordinary agricultural soil takes up about 50 parts of water and this is good enough for normal plant growth.

Soil Air. Free space must be available for diffusion of gases—carbon dioxide and oxygen—through soils, the former to escape into the atmosphere above and the latter to come in close contact with all parts of roots, protozoa, earthworms, etc., in order that they may respire and remain alive and active. Soil air is usually richer in CO_2 and poorer in O_2 than the atmospheric air. But in poorly aerated soil the concentration of CO_2 may be as high as 10% and that of O_2 as low as 10%, as against 0.03% and 20% of CO_2 and O_2 respectively in the atmospheric air. Growth of most plants is retarded under this condition. Proper aeration of the soil is, therefore, a necessity for normal growth of plants.

Capillarity. The capillary power of soils to draw water from below upwards depends on their texture The maximum rise is exhibited by medium-sized grains such as silt, and not by finer-grained or coarser-grained soils. It has been estimated that over a period of 18 days the capillary rise is 63 cm. in the case of sand, 84 cm. in the case of clay and 252 cm. in the case of silt (loam). The soils were air-dried in all cases. Initially, however, for a period of one hour sand shows more rapid capillary movement.

Experiment 4. **Water content of the soil.** To find out the water content of the soil the following procedure may be adopted. Collect from a depth of 0 3 to 1 metre

a small sample of soil by digging the earth and keep it in a stoppered jar. Take out a small lump from it and weigh it. Heat it at 110° C. for a while stirring the mass occasionally. All the water will be driven out by then. After cooling take the weight of the soil again. To make sure that all the water has been driven out, heat the soil again. A constant weight will indicate the loss of all the water from the soil. The difference in weight will indicate the quantity of water originally present in the soil. Then calculate the water content on a percentage basis.

Experiment 5. *Water holding capacity of the soil by capillarity.* Crush a lump of air-dry soil to break up the clay aggregates, but do not grind it. Take a circular brass box ($5\frac{1}{2}$ cm. in diameter by $1\frac{1}{2}$ cm. in height) which is perforated at the bottom. Place a filter paper at the bottom of the box and transfer the soil in small quantities at a time, gently pressing it after each addition, until the box is nearly full. Place it in a petri dish and add water to the dish to a depth of 1 cm. After a time add water again, if necessary, to restore the above depth and maintain it. After a period of 12-24 hours weigh the box after wiping the outside of it and deducting the weight of the filter paper. Then heat the box at 110° C. to drive off the water. Cool in a desiccator and weigh it again, deducting the weight of the filter paper. The weight of the box may be determined before or after the experiment. The weight of the soil after saturation with water *minus* that taken after heating will indicate the moisture content of the soil, i.e. the amount of water held by the soil particles. Then calculate the moisture content on a percentage basis.

Chemical Nature. Chemically the soil water contains, dissolved in it, a variety of *inorganic salts* such as nitrates, sulphates, phosphates, chlorides, carbonates, etc., of potassium (K), calcium (Ca), magnesium (Mg), sodium (Na) and iron (Fe), and of the 'trace' elements like boron (B), manganese (Mn), copper (Cu), zinc (Zn), aluminium (Al), molybdenum (Mo), etc. These salts, when analysed, are generally calculated in terms of oxides, and these often occur in the soil in very low percentages—less than 1; 'trace' elements mostly occur in .002-.0001%. Further, many of these remain in the soil in a variety of complex chemical forms and are not available to plants. In nature, however, the nutrient salts are very widely distributed. In the absence of any of the required compounds the plant suffers. A certain amount of *organic compounds*, chiefly proteins and their decomposition products, derived from the waste products of animals and dead bodies of plants and animals as a result of oxidation by soil bacteria and fungi, is present in the soil. *Humus* (see p. 242) contains a certain amount of organic food. *Acidity* and *alkalinity* of the soil are no less important for plant growth than the availability of plant food in the soil. Soils containing a high amount of lime (calcium carbonate) are alkaline, and soils containing a high quantity of humus are acid. These conditions can, however, be altered by the addition of one or the other, as the case may be. Most of the field crops prefer a slightly acid soil. Some grow well in a neutral soil; leguminous crops always prefer a slightly alkaline soil; while bananas and rhododendrons require distinctly acid soils for their

normal growth. The acidity or alkalinity of the soil may be tested with litmus papers or by a special method devised for the purpose.

Soil Organisms. Various kinds of bacteria are present in the soil, sometimes to the extent of a few million individuals per gram of soil, particularly in the region of organic matter, and many of them are useful agents of soil fertility. Thus nitrifying bacteria convert proteins of dead plants and animals into nitrates, and it is a fact that but for the activity of such bacteria the proteins would have remained locked up in the soil as such without being used. Then there are nitrogen-fixing bacteria, ammonifying bacteria, sulphur bacteria and a host of other types in the soil. Fungi are also abundant in the soil, particularly in the acid soil often replacing bacteria. Like the bacteria they are also useful agents in decomposing proteins. Many algae are also present in the soil. It is now definitely known that many of the blue-green algae fix atmospheric nitrogen in the soil. Among animals the soil-dwellers like many protozoa, earthworms, rats, etc., are useful agents in altering the soil. The burrowing animals make the soil loose for better aeration and percolation of water.

Humus. [illegible]
It consis[illegible]
with pro[illegible]
from dead roots, trunks, branches and leaves, under the action of various types of soil bacteria and fungi. Humus usually forms a surface layer, sometimes of some depth, as in forests and swamps. It is of considerable importance to plants both chemically and physically. The nitrogenous organic compounds of the humus are acted on by various bacteria and fungi and finally converted into nitrates which are absorbed by plants. Humus, therefore, is a source of plant food.
[illegible]
like clay particles it has also a great capacity for [illegible] taining water to the extent of 190 parts of its own weight. Thus, added to sandy soil it increases its water-holding capacity and added to clay soil it loosens its compactness and increases porosity for better aeration. Soil containing 5-15% of humus is suitable for agricultural crops. It is the seat of most of the bacterial processes in the soil.

Experiment 6. Humus content of the soil. To find out the humus content of the soil proceed as follows (ignition method). After heating a lump of soil at 110° C. to drive off the water cool it in a desiccator and then take its weight. Next in a
[illegible]
(Organic matter [illegible] nitrogen, sulphur dioxide and carbon dioxide and escape as such.) After complete combustion cool it in a desiccator and then weigh it again. The loss in

weight almost approximately represents the quantity of humus originally present in the soil sample. Then calculate the humus content of the soil on a percentage basis. The residue left after combustion is the incombustible or inorganic matter present in the soil.

Fertility of the Soil. A soil may be regarded as fertile when all the conditions—physical, chemical and biological—are satisfied. Absence of any one of them acts as a limiting factor and thus affects normal growth of the plant, and the crop as a whole suffers. Composition of the soil lying within the following limits (given in terms of volumes) may be considered good: mineral particles—50-70%, pore space (containing water and air)—30-50%, and organic matter (humus)—5-15%, with the following essential elements occurring in the following proportions: N—0.1-0.5%, P—0.08-0.5%, K—1.5-3.0%, Ca—0.1-2.0%, Mg—0.3-1.0%, S—0.01-0.14% and Fe—a trace. Oxygen and carbon (the latter as CO_2) are of course obtained from the air.

Fertilizers. Ordinarily the soil contains the necessary salts required by plants. Deficiency, however, sometimes occurs in one or more of them, particularly in nitrogen, phosphorus, potassium and calcium, mainly due to gravitational pull of the soil water, heavy drainage and intake by roots, and to make good this deficiency the use of fertilizers or manures becomes a necessity. Fertilizers are certain chemical substances which when properly added to the soil make it fertile, i.e. enable it to produce more abundantly. Production may be doubled or even trebled by proper use of chemical fertilizers. Manuring of the field for better crop production may be done by any of the following three methods. (1) Artificial manuring is done by introducing into the soil particular chemical compounds or their mixtures in suitable proportions according to deficiencies. Commonly ammonium sulphate, superphosphate, leaf-compost, bonemeal, oil-cakes, etc., are used as chemical fertilizers. (2) Farmyard manuring is done by adding cowdung and organic refuses to the soil. (3) Green (natural) manuring is done by growing certain leguminous plants in the field (see rotation of crops, pp. 252-3).

Sulphate of ammonia is now extensively used as a chemical fertilizer for many of the field crops like rice, barley, potato, sugarcane, tea, orange, cabbage, cauliflower, turnip, mustard, etc. This chemical becomes quickly nitrified in the soil in course of a few days and changed to calcium nitrate. It, however, makes the soil acid and, therefore, unsuitable for many crops. The remedy, however, lies in adding lime to the soil. Ammonium sulphate is not washed out of the soil even by torrential rains. Nitrate of soda is also another source of nitrogen for field crops. The Sindri Fertilizer Factory at Sindri (Bihar) was constructed in 1951 and will shortly be producing 400 tonnes of ammonium sulphate and 70 tonnes of urea daily. Trombay Fertilizer Plant (near Bombay) is expected to produce 99,000 tonnes of urea and 3,30,000 tonnes of nitrophosphate a year when its full capacity is reached.

Chapter 3 CHEMICAL COMPOSITION OF THE PLANT

The various elements that have entered into the composition of the plant body may be determined by chemical analyses, and those essentially required by the plant determined by water culture experiments.

1. **Chemical Analyses.** By chemical analyses of a plant we can find out the various elements that have entered into its composition For this purpose a representative sample of the plant (i.e. a sample representing all parts of the plant body) is taken and it is dried at 110° C. or so. All the water that the plant contains is thus driven off. Then, by careful weighing, the proportion of water to the total weight of the plant is determined. Plants in general are found to contain a high percentage of water—in woody parts about 50 per cent, in soft parts about 75 per cent, in succulent parts from about 85 to 95 per cent, and in water plants 95 to 98 per cent. When the plant is *charred* we get charcoal. The main bulk of this charcoal is **carbon**; in fact, almost half the dry weight of the plant is carbon. The dried plant is then carefully burnt over a flame at a temperature of about 600°C. On thus burning, the **organic compounds** such as the proteins, carbohydrates, fats and oils, etc., being combustible, are converted into carbon dioxide, water vapour, sulphur dioxide and ammonia or free nitrogen, and escape as such. These gases may be collected by proper methods and their composition studied. *Proteins* when analysed are seen to contain **carbon** (C), **hydrogen** (H), *oxygen* [illegible]

[illegible]

pounds which [illegible]
of ash varies [illegible]
the same plan[illegible] of the ash show that, of the 92 well-known chemical elements occurring in nature, about 40, possibly more, are present in it. Most of these elements occur in very minute quantities and their presence too is not very constant. The following, however, are constantly found in the ash of the plant, occurring of course in varying proportions in different plants: [illegible]
(Fe) and sodium [illegible]
(P), chlorine (C[illegible] [illegible]aces only are: boron [illegible]
certain other [illegible]
(B), manganes[illegible], *molybdenum* (Mo),
aluminium (Al[illegible] elements (see p. 253).

Chemical analyses of the plant body (including the combustible

material and the ash) show that, of the various elements present in it in easily detectable and measurable quantities, the following 13 elements are constant in all plants: potassium, calcium, magnesium, iron and sodium among the metals, and carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, chlorine and silicon among the non-metals. Besides, some of the 'trace' elements which are now known to be constant in green plants are: boron, manganese, zinc, copper and molybdenum. Aluminium though not constant is also very widespread in plants. The average chemical composition of the plant body may be given thus: carbon—45.0%, oxygen—42.0%, hydrogen—6.5%, nitrogen—1.5% and ash—5.0% (after Maximov).

ater Culture Experiments. Water culture experiments are carried) ascertain which elements are essentially required by plants for normal growth, and which only incidentally absorbed. These iments further help us to understand the forms (chemical comds) in which they are best taken up, the particular concentra- of the solute, and the source of supply (soil or air) of these eles. Water culture experiments consist in growing some seedlings ater containing some known salts in particular proportions, m as normal culture solution, and studying the effect produced em (seedlings) regarding growth and development. Normal cul- solutions of various compositions are used (Sachs 1860, Knop , Pfeffer 1887). The following composition has been ~~worked out~~ nop as forming the normal water culture solution, that is, the ion required by the ~~seedlings for~~ their normal growth.

's normal culture solution

Potassium nitrate, KNO_3	[illegible] gm.
Acid potassium phosphate, KH_2PO_4	1 gm.
Magnesium sulphate, $MgSO_4$	1 gm.
Calcium nitrate, $Ca(NO_3)_2$	4 gms.
Ferric chloride solution, $FeCl_3$	a few drops
Water	1,000 c.c.

is is a stock solution of 0.7% strength. To make a 0.1% solu- which is suitable for water culture experiments add 6,000 c.c. ater to the stock solution.

7 riment 7. Water culture experiments. A series of bottles or jars of the same nd shape are fitted each with a split cork. A number of seedlings of the kind and more or less of the same size are taken. The bottles marked C, D, etc., are filled with culture solutions of known composition. Through plit cork a seedling is introduced into each bottle. The bottles are wrapped black ~~paper and~~ exposed to light. Arrangements should be made for proper ion of the roots. It is desirable that the culture solution should be renewed ightly. The following table shows the nature of solutions used and the effect uced on the seedlings. PH — [illegible] or made [illegible]

A with normal culture solution	Growth of the seedling is normal.
B the same minus potassium salts	Growth becomes checked; leaves lose their colour; the seedling withers; and carbohydrate formation is slow.
C the same minus calcium salts	Root system does not develop properly; leaves become yellowish, spotted and deformed; and the seedling becomes short and weak, and is liable to be easily diseased.
D the same minus magnesium salts	Chlorophyll is not formed; the seedling becomes stunted in growth; and carbohydrate formation is slow.
E the same minus iron salts	Seedling becomes chlorotic.
F the same minus phosphorus compounds	Growth is slow and the seedling begins to weaken.
G the same minus sulphur compounds	Leaves yellowish and stem slender.
H the same minus nitrogen compounds	Seedling is weak and straggling, and leaves yellowish.

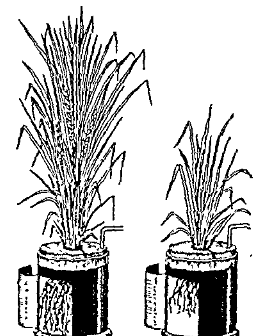


FIG. 4. Water culture experiments; *left*, in normal solution; *right*, in the same minus one of the essential elements.

Inference. Water culture experiments prove conclusively that a plant can grow satisfactorily only when it is supplied with K, Ca, Mg, Fe and H, O, N, S, P. These experiments thus help us to understand that these elements (together with C) are essential, while others are non-essential being only incidentally absorbed; they show further that these elements are absorbed in soluble compounds, in suitable proportions and in very dilute solutions, occurring in the soil; that free oxygen and carbon dioxide are obtained from the air (and not from the soil)—oxygen for the respiration of the living cells and carbon dioxide for the manufacture of food by the green cells; that free nitrogen of the air is of no use to the plant; and that the plant must be exposed to light. Chemical analyses give us no clue to any of the above-mentioned facts.

Sand or Charcoal Culture Experiments. To obviate many difficulties in water culture experiments it has become the growing practice with physiologists to take to sand or charcoal culture. Charcoal is thoroughly washed and powdered. In

the case of sand, it is washed, dried and then ignited to remove organic impurities. Normal culture solution is added to any of the two media and growth of the seedling studied. The effect produced on the seedling under the exclusion of a particular element is studied in the same way as in water culture experiments.

Essential and Non-essential Elements. Chemical analyses of the plant reveal the presence of a long list of elements in it, while water culture experiments prove that *ten elements* (including carbon which is obtained from the air) are essential for normal growth of all plants. Of the trace elements boron, manganese, zinc, copper and molybdenum are also now regarded as essential (see p. 253). Thus the total number of elements now considered essential are 15 (see list below). Other elements present in the plant body are non-essential. It should, however, be noted that certain plants require for their normal growth one or more elements other than the established 15 essential elements.

Classification of Elements

Essential. metals—K, Ca, Mg and Fe.
non-metals—C, H, O, N, S and P.
Non-essential: metal—Na.
non-metals—Cl and Si.
Trace (essential): metals—Mn, Zn, Cu and Mo.
non-metal—B.

Role played by the Elements in the Plant Body. (1) *Potassium* is abundantly present in the growing regions. It is essentially a constituent of the protoplasm and is closely connected with its vital activity. It is, however, absent from the nucleus and the plastids. Potassium is known to act as a catalytic agent in the synthesis of carbohydrates and proteins; starch grains are not formed in the absence of potassium. Potassium helps the growth of the plant and enables it to produce healthy flowers, seeds and fruits. In the absence of potassium the growth of the plant is checked; the stem becomes slender and the leaves lose their colour and gradually wither. Potassium nitrate and possium chloride are the usual forms in which potassium is absorbed by plants. Water lettuce (*Pistia*), when burnt, yields about 12% of potash, and is used as a valuable manure.

(2) *Magnesium* helps in the synthesis of phosphorus-contai[illegible] lipid substances which are important constituents of protopl[illegible] is present in the chlorophyll to the extent of about 5.6% by [illegible] and, therefore, in its absence chlorophyll is not formed, [illegible] becomes stunted in growth. It is present to a considerabl[illegible] the seeds of cereals and leguminous plants.

(3) *Calcium* is always present in green plants. It [illegible] wall, particularly in the middle lamella, as calci[illegible] ful in neutralizing acids which would otherwise [illegible] plants. It helps to maintain the semi-permeab[illegible] It is also anti-toxic to various poisonous sub[illegible]

the growth of roots. Plants like lemon, orange, shaddock, etc., grow well in a soil rich in calcium (lime). Fruits in general, and stone-fruits in particular, require plenty of calcium (lime) for their normal development. The stone of the stone-fruit very often does not form in the absence of lime in the soil. In general plants become stunted in growth in the absence of calcium. Many plants, however, cannot stand a high amount of calcium in the soil, and they become chlorotic in consequence.

(4) **Iron** is essential for the formation of chlorophyll although it is not present as a constituent. It may be associated with the plastids. Iron is always present in the protoplasm and in the chromatin of the nucleus.

(5-6). **Sulphur and Phosphorus.** Sulphur is a constituent of an amino-acid, cystine, which is one of the compounds forming plant

[illegible]

concerned in carbohydrate breakdown in respiration. Phosphorus aids nutrition and hastens maturity and ripening of fruits, particularly of grains. It promotes the development of the root system. Underground organs like radish, beet and potato require phosphorus for their normal development. Sulphur is absorbed as sulphates of some metals and phosphorus as phosphate of calcium or potassium.

(7) **Carbon** forms the main bulk—45% or even more—of the dry weight of the plant. It is the predominant constituent of all organic compounds which are, in fact, known as compounds of carbon. Carbon is absorbed from the atmosphere as carbon dioxide. Although carbon dioxide occurs in the air to the extent of only 0.03%, still air is the only source of all the carbon for the plant, as proved by water culture experiments. It is to be noted that there is a regular circulation of carbon dioxide and oxygen between the plant and the atmosphere, and two processes are connected with it: one is photosynthesis and the other is respiration. In photosynthesis *green* plants take in carbon dioxide from the atmosphere *during the daytime* and give off oxygen. (The oxygen that is given off in the process is, however, released fr[illegible] the atmosphere to become [illegible] oxygen. In the reverse process, i.e. in respiration, all plants and animals take in oxygen from the atmosphere *at all times* and give off carbon dioxide. In the combustion of coal and wood also carbon dioxide is given out to the atmosphere. Thus the atmosphere has a tendency to become richer in carbon dioxide and poorer in oxygen. It is evident, therefore, that by these two processes the *total* volumes of these gases are kept constant in the air. The circulation of carbon

by the above two processes through the green plants (and animals and non-green plants, and also by the chemical combustion of non-living material, e.g. coal) ~~and the atmosphere is spoken of as carbon-~~ cycle.

(8) **Nitrogen.** Although nitrogen occurs to the extent of about 78 parts in every 100 parts of air by volume, it is not as a rule utilized by plants in its free state. It may enter the plant body through the stomata with other gases, but it comes back unused. Although nitrogen is so abundant in the air, *it occurs in the dry substance of the* plant to the extent of 1-3% only. Nevertheless, it is indispensable to the life of the plant, as it is an essential constituent of proteins, chlorophyll an [illegible], more particularly [illegible] nsiderably in the abs[illegible] this element leaves [illegible] ises vigorous growth of vegetative parts, specially the leaves, but delays reproductive activity. Plants become readily susceptible to the attacks of fungi and insects in the excess of nitrogen.

Nitrogen of the Soil. The amount of nitrogen in the soil varies from 0.096 to 0.21% (average Indian soil contains about 0.05% of nitrogen); still soil is the main source of nitrogen for the plant. Here it exists as *inorganic* and *organic* compounds. The chief forms of inorganic compounds are the nitrates and nitrites of potassium and calcium, *and also ammonia and its compounds; while the organic* compounds are chiefly the proteins. Normally the ammonium compounds present in the soil are made available for the use of the green plants after conversion into nitrate by the action of certain micro-organisms—the nitrifying bacteria—which live in the soil. The process is called **nitrification.** In this process the ammonium compounds are oxidized into nitrate in two stages: (*a*) these are acted on by the nitrite-bacteria (*Nitrosomonas*) and oxidized into nitrite ($-NO_2$), and (*b*) the nitrite thus formed *is again acted on by the* nitrate-bacteria (*Nitrobacter*) and further oxidized into nitrate ($-NO_3$). The nitrate, thus produced, is readily absorbed by green plants. *In certain types of soils, however,* ammonium compounds are the chief forms in which nitrogen is readily absorbed by plants. A portion, however, of the ammonium compounds is disintegrated by denitrifying bacteria into free nitrogen which then escapes into the atmosphere (**denitrification**).

The chief forms of organic compounds of nitrogen are the various kinds of proteins. Dead bodies of animals and plants containing proteins are decomposed by different putrefying bacteria and also to some extent by certain fungi *present in the soil. In the first stage, in the absence of oxygen,* the proteins are reduced to amino-acids then to ammonium compounds (**ammonification**) by the putrefy-

bacteria and fungi; and in the second stage, *in the presence of oxygen*, the ammonium compounds undergo nitrification, as stated above. The nitrate, thus produced, is readily absorbed by green plants.

Test for Nitrates. The presence of nitrates in the plant tissue or in the soil is easily detected with diphenylamine. A 0.5% solution of it in strong sulphuric acid turns nitrates blue

Ammonia of the Air. It has been suggested that ammonia of the air may be an important source of nitrogen for the soil. It is absorbed by some of the constituents of the soil, nitrified there and made available to plants in the form of nitrate. It is a known fact that acid soils always absorb ammonia from the air. Sea water releases ammonia during evaporation, which soon condenses on the surface of the soil, particularly cultivated soil. Ammonia of the air may, therefore, be regarded as one of the sources of nitrogen for the soil, particularly in the neighbourhood of the sea.

Fixation of Atmospheric Nitrogen. Under certain circumstances the gaseous nitrogen of the air may combine with other elements and is ultimately made available to the plants as compounds of nitrogen in the [illegible] lows: [illegible] 1837), [illegible] Beijerinck 1901), (3) activity of symbiotic bacteria (Hellriegel and Wilfarth 1887), and (4) activity of blue-green algae (P. K. De 1944).

1. **Nitrogen Fixation by Electric Discharge.** The free nitrogen of the air to some extent becomes available to the green plants by the discharge of electricity (lightning) during a thunderstorm. Under the influence of electricity nitrogen of the air combines with oxygen to form nitric oxide—$N_2+O_2=2NO$ (nitric oxide). This nitric oxide at once unites with oxygen of the air and forms nitrogen peroxide—$2NO+O_2=2NO_2$ (nitrogen peroxide). The nitrogen peroxide, thus produced, is then dissolved by falling rain forming nitrous acid (HNO_2) and nitric acid (HNO_3)—$2NO_2+H_2O=HNO_2+HNO_3$, and washed down into the soil. Here they combine with some metal like potassium or calcium, and form respectively nitrite and nitrate of potassium or calcium. Nitrate is directly absorbed by plants; while nitrite is oxidized into nitrate by nitrate-bacteria. On an average rain-water brings down to the soil about 4 kilograms of nitrogen per year per hectare.

2. **Nitrogen Fixation by Saprophytic Bacteria of the Soil.** Various types of nitrogen-fixing bacteria present in the soil have the power of fixing free nitrogen of the soil-air in their own bodies in the form of amino-acids and finally building up proteins from them. After the death of these bacteria the proteins are released to the soil. In due [illegible]

But it must be noted that the amount of free nitrogen fixed by the saprophytic bacteria is much less than that fixed by the symbiotic

bacteria. There are two distinct groups of saprophytic bacteria—aerobic and anaerobic. Several species of *Clostridium* (anaerobic) first discovered and named by Winogradsky (1893) and *Azotobacter* (aerobic) first discovered and named by Beijerinck (1901) are typical of these two groups. These bacteria are widely distributed in soils. The efficiency of nitrogen-fixation by these bacteria depends on *the oxidation of carbohydrates (particularly sugars) in the soil as a* source of energy. The chemistry of nitrogen fixation is not, however, definitely known.

3. **Nitrogen Fixation by Symbiotic Bacteria: Nodule Bacteria of** ***Leguminosae.*** Agriculturists have noted for a long time that leguminous plants such as pulses grown in a soil make it fertile and lead to an increase in the yield of cereals. It was later discovered by Hellriegel and Wilfarth in 1887 that the roots of these plants possess some swellings, called **nodules or tubercles,** which are infected with some types of nitrogen-fixing bacteria, particularly the different species of *Rhizobium,* and these bacteria have the power of fixing the free nitrogen of the soil air in the said nodules. It is to be particularly noted

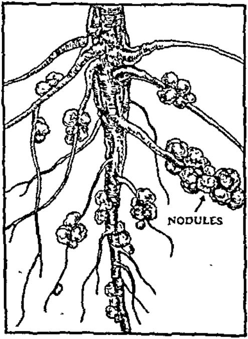


FIG. 5. Nodules of a leguminous plant.

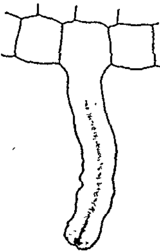


FIG. 6. A root-hair infected with bacteria. Note the bacterial thread.

that neither the leguminous plants nor the bacteria can fix nitrogen by themselves. It is now known that such bacteria are present in the nodules of most plants (but not all) of *Leguminosae,* particularly of *Papilionaceae,* and in the roots of a few other plants. The mode of

infection of the root by these bacteria and of nodule formation is as follows. Bacteria enter through the tip of the root-hair. After penetrating into it they form into a sort of thread consisting of innumerable bacterial cells held together by mucilage. This thread passes down the hair and reaches the cortex of the root perforating the cell-walls. Bacteria then multiply in number and colonize the cortex. Cortical cells are stimulated to grow, perhaps due to the secretion of some stimulant by these bacteria, and thus give rise to small swellings or nodules of varying sizes and fix in them the nitrogen of the air in the form of some amino-compounds. A portion of the amino-compounds is absorbed into the plant body, another portion is excreted out of the nodules and the remaining portion remains locked up in the nodules. Thus the soil becomes richer in nitrogen, more particularly so, if the nodule-bearing leguminous plants are ploughed into the soil. The leguminous plants supply the bacteria with carbohydrates, and the bacteria supply the former with nitrogenous food; so this is a case of symbiosis (see p. 19). It is, however, to be noted that the initial chemical changes leading to the formation of amino-compounds in the nodules are not clearly understood.

4. **Nitrogen Fixation by Blue-green Algae.** It is now definitely known that certain members of Myxophyceae, particularly several species of *Nostoc* and *Anabaena*, which are common in many soils, apart from [illegible] rice-fields, these algae are particularly common and they contribute to the fertility of such soils.

Nitrogen Cycle. Although plants are continually absorbing salts of nitrogen from the soil it should not be supposed that the nitrogen contents of the soil would sooner or later become exhausted. Under natural conditions the soil soon becomes replenished of this element. This is so because of the fact that there is a regular circulation of nitrogen through the air, soil, and plants and animals. Nitrogen in the soil is, therefore, inexhaustible. We have already seen how the free nitrogen of the air is brought down into the soil as ultimate products of nitrite and nitrate of some metals. Nitrates are absorbed by plants and made into proteins in their body. Plant proteins are taken up by animals. After the death and decay of animals and plants the proteins contained in their body are again converted into nitrates in several stages (see p. 249), and absorbed as such by plants again. At the same time a portion of the ammonium compounds present in the soil is disintegrated by denitrifying bacteria into free nitrogen or oxides of nitrogen which then escape into the surrounding air. This free nitrogen is again brought down into the soil from the air.

Rotation of Crops. The fixation of atmospheric nitrogen in the soil is of very great agricultural importance. Most crops absorb the nitrogenous compounds from the soil and impoverish it. Leguminous plants, on the other hand, enrich

it in nitrogen when their nodule-bearing roots are left in the soil. Thus leguminous crops such as pulses, *Sesbania cannabina* (B. DHAINCHA), cow pea (*Vigna sinensis*), etc., are grown in the field in rotation with the non-leguminous crops such as cereals (rice, wheat, maize, barley, oats, etc.) and millets. Root crops such as turnip, radish, beet, etc., take plenty of potash, calcium and nitrogen from the soil.

Trace- or Micro-elements. It is now definitely known that at least five 'trace' elements such as boron, manganese, zinc, copper and molybdenum are essential for normal growth of plants. The absence of any of them in the culture solution or in the soil leads to abnormal growth and to certain plant diseases. It may also be mentioned that aluminium though not recognized as essential is very widely distributed among plants. The normal culture solution, however, does not include any of the 'trace' elements, and still the plant grows. How to explain it? It is likely that some of the so-called pure chemicals used by the early workers contained traces of these elements. Distilled water commonly used in the water culture experiments might have contained traces of them. Traces of some of these elements might have dissolved out of the glass bottles and other vessels containing the chemicals and the solutions. Besides, seeds themselves are likely to contain these elements in their cotyledons or endosperm. Thus the sources of contamination of the water culture solution being many, such elements crept into the solution undetected. In recent times by using extra-pure chemicals, re-re-distilled water and special glass bottles it has been proved beyond doubt that the five elements, mentioned above, are indispensable and essential for all green plants.

Boron. This is possibly required by all plants. The beneficial effect of boron has been proved in a number of cases, e g. tomato, tobacco, lemon, beet, turnip, mustard, cotton, etc. Cauliflower is in particular need of boron, while cereals have a very low requirement for it. Boron helps the formation of root-nodules in leguminous plants, and it improves the yield of sugar in beet. In its absence beet suffers from 'heart rot', tobacco from 'top rot', potato from 'leaf roll'. In general, in its absence the growth of the plant is retarded and the leaves become spotted. Its absence particularly affects the apical meristems, i.e. the root-tip and the stem-tip, which become brittle and die off.

Manganese. Absence of this element or its deficiency results in drying up of leaves, weak growth of the plant, poor bloom, chlorosis and certain diseased conditions of leaves. There is always an appreciable amount of manganese in orange, lemon and tomato. There is a relationship between manganese and oxidation enzymes. Cabbages require manganese while, as stated above, cauliflower is in need of boron. In pines and allied plants there is comparatively a high percentage of manganese. This element particularly benefits the leguminous plants.

Zinc. Absence of zinc results in stunted growth of the leaf and the shoot, mottling of leaves, drying back of the growing tips and also various physiological diseases. Cells of leaves also do not utilize carbohydrates in respiration in the absence of zinc. The beneficial effect of zinc has been already proved in a number of cases, e g., cereals, lettuce, pea, bean, lupin, beet, potato, kohl-rabi, tomato, and many fruit trees. Zinc occurs more abundantly in green tissues than in other parts and helps the formation of chloroplasts, as [illegible]

do

effect of copper has been already proved in flax, tomato, barley, etc. Deposit of copper after spraying helps the formation of starch in the underlying tissues. Except in very dilute solutions copper salts are highly toxic.

Molybdenum. Molybdenum is known to be essential for plant growth. The first sign of the deficiency of this element is the formation of chlorotic or necrotic areas in the leaf. It has been claimed that this element is required in the cells for the reduction of nitrate to ammonia for protein synthesis. On this basis it is considered to enter into the composition of enzymes. There is also evidence that this element is required for nitrogen-fixation by *Azotobacter* and *Rhizobium*.

Aluminium. Aluminium has been found in the ash of many plants in a very small percentage, specially in wheat, maize, rye, bean, lentil, carrot, cabbage, turnip, lettuce, sunflower, etc It is, however, found in a large quantity in the ash of *Lycopodium* Aluminium is found in almost all parts of the plant body, more so in the root and the leaf. It occurs mainly in the protoplasm and the nucleus. Aluminium in very low concentration stimulates growth, while in higher concentration it is toxic. It influences the colour of the flower.

Chapter 4 ABSORPTION OF WATER AND MINERAL SALTS

Roots and leaves are the main absorbing organs of plants. Roots absorb water and dissolved mineral salts from the soil and leaves take in oxygen and carbon dioxide from the atmosphere.

1. **Water and Inorganic Salts.** Green plants absorb water and inorganic salts from the soil by the unicellular root-hairs which pass irregularly through the interstices of the soil particles and come in close contact with them. Absorption is also actively carried on by the growing regions of the roots. Maximum absorption of soil water takes place through the root-hairs and also the zone of cell enlargement, while maximum absorption of inorganic salts takes place through the zone of cell division (see FIG. I/3). Water is absorbed in large quantities, always in excess of the requirements of the plant. Small quantities of various soluble inorganic salts such as nitrates, chlorides, sulphates, phosphates, etc., dissolved in the soil water are [illegible] noted

[illegible]

intake of salts may be comparatively small. The absorption of water is not correlated to the accumulation of salts in the cells. The absorbing surfaces of cells must be such as to allow ready passage of water and dissolved salts through them. In this connexion the membranes of an absorbing cell may be recalled to mind: the membranes are the

cell-wall, the plasma membrane (ectoplasm) and the tonoplasm. The cell-wall is easily permeable to water and is also minutely perforated, while the other two membranes although very thin and delicate and possibly made of phospholipids possess the property of selective permeability.

The substances that are absorbed from the soil may be classified into two groups: the first group consists of water (and also sugars so far as other absorbing cells of the plant body are concerned) which undergo no or little ionization and they may enter the cells by following the simple laws of diffusion and other physical processes, while the second group consists of mineral salts which undergo extensive ionization. The ionized particles of such salts are taken up by the cells where they accumulate, sometimes in heavy concentration; the ions may travel as such or they combine into suitable compounds.

Availability of Soil Water. A portion of the water moves downward in response to the force of gravity, rapidly through sandy soil and slowly through loam or clay soil, and carries down or sometimes even washes out a considerable quantity of essential food elements. This moving water percolates through the interspaces of large soil particles and is not of any use to the plant as root-hairs cannot absorb it. Then again each soil particle holds some water within it by the force of imbibition (see p. 232): this water is known as *hygroscopic water*. It is held so tenaciously by the soil particle that the root-hairs cannot dissociate it from the particle. This hygroscopic water also is not of any use to the plant. Surrounding each soil particle there is a thin or sometimes thick film of water, loosely held to it by capillary force; this is known as *capillary water*. It also occurs in the spaces between the soil particles. This capillary water together with the various nutrient salts dissolved in it can be readily absorbed by the root-hairs and is, therefore, regarded as the principal source of supply of water to the plant. Capillary water may move from particle to particle in any direction. If this capillary water diminishes in quantity the plant suffers and even death may occur due to wilting. It must, however, be noted that capillarity cannot raise water for more than 1 or 2 metres from the deeper water level of the soil, except near tanks, lakes and rivers; capillarity still remains useful in the cases of deep-rooted plants.

2. **Gases.** Of the various gases present in the air[1] it is only the oxygen and the carbon dioxide that diffuse into the plant body and are finally utilized by the plant. Other gases may similarly diffuse into the plant body, but they are returned unused. Oxygen is utilized by

[1] **Composition of the Air.** Of 100 parts of air by volume nitrogen occupies 78%, oxygen 21%, carbon dioxide 0.03%, and other gases such as hydrogen, ammonia, ozone, aqueous vapour, etc., occur in traces only.

all the living cells of the plant for respiration at all times; but carbon dioxide is utilised by only the green cells for the manufacture of carbohydrates during the daytime only.

Soil and Root. The repeated branching of the root, its ramifications in all directions and penetration downward, coupled with the production of root-hairs in enormous numbers help the plant to absorb a huge quantity of water, etc., from the soil. It has been estimated that the total length of the root system of a plant may extend up to several kilometres, and in some cases a few hundred kilometres. Many millions of root-hairs, each coming in intimate contact with many soil particles, may be formed by a single plant, thus enormously increasing the absorbing area of the root. The plant has thus developed an elaborate system for the intake of water and mineral salts from the soil. It is the root-hairs and the tender growing regions of the roots that are utilized by plants for the purpose of absorption; the older parts of the roots, being impervious to water, are of no use in this respect. Root-hairs vary in length from a few millimetres to a few centimetres, and are composed of cellulose and pectic compounds. Soil particles strongly adhere to the root-hairs in the presence of the latter compounds.

Absorption of Water. Water adheres to the soil particles with some force (see p. 255), particularly so when there is scarcity of it in the soil. Clay and humus retain water very tenaciously. There must then be some stronger forces for dissociation of this water from the soil particles and its uptake into the root-hairs. The forces concerned are diffusion (see p. 232), imbibition (see p. 232) and osmosis (see p. 232). According to most authors diffusion is not regarded as an important mechanism of absorption, while imbibition and particularly osmosis are regarded as very important in this respect. **Parts played by root-hairs** (FIG. 7). In the case of root-hairs which contain some sugars and salts in solution, the cell-sap is stronger than the surrounding soil water. The two fluids (cell-sap and water) are separated by the cell-membrane (cellulose cell-wall + plasma membrane). As a consequence osmosis is set up. There is a flow of water from the soil into the root-hairs through the intervening cell-membrane (endosmosis). Osmosis, however, is not in this case a purely physical process. Al-

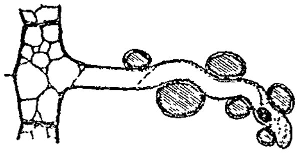


FIG. 7. A root-hair with soil particles adhering to it. Each particle is surrounded by a film of capillary water.

though the cell-wall is permeable to both the water and the solutes, the plasma membrane is but differentially and selectively permeable, allowing the water to flow in, while stopping the sugars and salts of the cell-sap from flowing out. This selective permeability is characteristic of the plasma membrane. The same membrane, however, varies in its permeability under different conditions.

Absorption of Mineral Salts. Several workers carrying on experiments on the physiological process of absorption of salts over a prolonged period (1917-44) have shown that inorganic salts are absorbed in the form of *ions*[1] although certain compounds, as experimentally proved by Osterhout and others, may as such enter the plant cell through the plasma membrane by the process of diffusion from the higher concentration of the soil solution to the lower concentration of the cell-sap. It has, however, been seen in many cases that the concentration of the cell-sap is higher than that of the soil solution. This being so, the process of absorption cannot be explained on the basis of simple diffusion (Stiles, 1924). The physico-chemical nature of the plant cell is very complex, changing continually in response to its environment, and at the same time the soil itself is a heterogeneous medium. So the forces concerned must be of varied nature. It is the modern tendency based on experiments to explain absorption on the basis of ions (+ and −) formed on the breakdown of molecules by electrolysis. The special feature of the living cells is that they can accumulate ions (and not salts) in them to a concentration far exceeding that of the surrounding medium. Actually several workers have proved it by experimental work on *Nitella* and other plants. This active accumulation of ions in the cells requires expenditure of energy to move the ions into the cells. The energy required is believed to be released by root-respiration. The concentration of ions in the cells is not even in all cases—the maximum accumulation being K^+ ions, others much less. It has been seen that soil colloids readily yield ions on electrolysis. It is to be noted that ions of both the electric charges must be taken up by the cells to maintain an electric balance both inside and outside the cells. It is also to be noted that the plasma membrane possesses the ability to select and permit the entrance of certain ions and greatly restrict others. Further an exchange of ions takes place

[1] Ions are atoms or groups of atoms which carry either a positive charge of electricity or a negative charge. When an ionizable material in water is subjected to electrolysis molecules of it break up into two or more ions of different kinds—those charged with positive electricity are said to be electro-positive ions such as K^+, Na^+, Ca^{++}, Mg^{++} and also H^+, and those charged with negative electricity are said to be electro-negative ions such as Cl^-, Br^-, NO_3^-, $H_2PO_4^-$, OH^- and SO_4^{--}. The process is reversible as the following examples will show: $NaCl \rightleftharpoons Na^+ + Cl^-$; $HCl \rightleftharpoons H^+ + Cl^-$. The breaking up of molecules may not always be complete.

between the ectoplasm and the soil solution; for example, a negative ion released by the ectoplasm establishes a *difference of potential* between the two media. Thus to equalize the *charge* the soil solution yields a positive ion to the ectoplasm.

Conditions. Absorption of salts depends on a number of conditions, viz. aerobic root respiration, light affecting photosynthesis, rate of transpiration, permeability of the plasma membrane, influence of temperature, hydrogen-ion concentration, etc.

Experiment 8. Absorption of water. (*a*) An interesting experiment may be carried out in the following way. Put a small lupin plant with white flowers or a cut branch of it in a glass cylinder filled with coloured solution (preferably water coloured with eosin) and watch. Within a very short time it will be seen that the white flowers turn pinkish—the colour of eosin—as a result of absorption of coloured water by the roots or by the cut end of the branch. *Peperomia* plant may also be similarly used, and streaks of red noticed through the stem.

(*b*) To demonstrate the rate of absorption proceed in the following way. Arrange the experiment, as shown in FIG. 15, and mark the level of water in the graduated tube. Note every few hours the gradual fall of the water level. At the end calculate the rate of absorption per unit of time. The experiment may be repeated under different conditions of light and temperature, and the rates of absorption compared.

Chapter 4 CONDUCTION OF WATER AND MINERAL SALTS

Root Pressure

The water that is absorbed from the soil by the root-hairs, whether by the process of osmosis or imbibition, gradually accumulates in the tissue of the cortex. As a result of this accumulation of water the cells of the cortex become fully *turgid*. Under this condition their walls which are composed of cellulose exert pressure on the fluid contents and force out a quantity of them towards the xylem vessels, and the cortical cells become *flaccid*. They again absorb water and become turgid and the process continues. Thus an intermittent pumping action goes on in the cortex of the root, and this pumping action naturally gives rise to a considerable pressure. As a result of this pressure the water is forced into the xylem vessels through the passage cells and the unthickened areas and pits that the endodermis and the vessels are provided with. Besides, the lignified walls of the vessels are also permeable by water. Root pressure *is thus explained*

as the pressure exerted by the cortical cells of the root upon their liquid contents under fully turgid condition forcing a quantity of them into the xylem vessels and through them upwards into the stem.

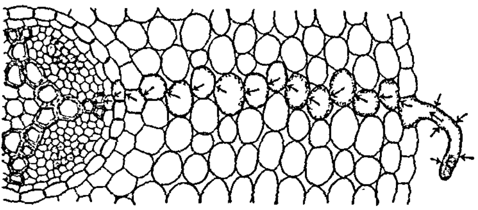


FIG. 8. A root in transection showing the course of water from the root-hairs to the xylem.

Experiment 9. Root pressure (FIG. 9). Cut across the stem of a healthy plant (preferably a pot plant) a few cm. above the ground in the morning, and fix to it, by means of a rubber tubing, a T-tube. Pour some water into the tube and freely water the soil. Fill a manometer (i.e. the U-tube with a long arm and a bulb) partially with mercury, as shown in the figure. Connect the manometer to the T-tube through a rubber cork. Insert a cork fitted with a narrow glass tube to the upper end of the T-tube. Make all the connexions air-tight by applying melted paraffin-wax. Seal the bore of the narrow tube and note the level of mercury in the long arm of the manometer. *Observation.* After a few hours note the rise of mercury-level in the long arm; also note the rise of water-level in the T-tube. *Inference.* The rise of mercury is certainly due to accumulation of water in the T-tube and the pressure exerted by it. This phenomenon is evidently due to exudation of water from the cut surface of the stem. This experiment thus shows that the water is *forced up* through the stem by root pressure.

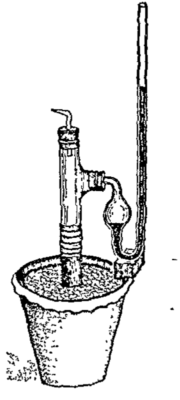


FIG. 9. Experiment on root pressure (qualitative).

Experiment 10. Quantity of exudate in root pressure. Arrange the apparatus, as shown in FIG. 10. The T-tube fitted with a bent side-tube and a stopcock at the upper end is fixed to the cut end of a stem through a rubber tube and tied or otherwise properly bandaged. The tubes are filled with water. Water the soil freely

and keep the apparatus in a shady place. Leave it undisturbed till the next day or the day after. Note the quantity of water that has accumulated in the measuring cylinder, say, within 24 or 48 hours as a result of root pressure.

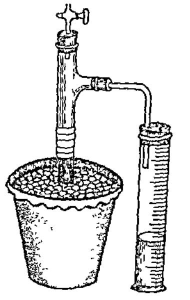


FIG. 10. Quantity of exudate in root pressure.

Root pressure is continually forcing up the water through the xylem (or wood), but it is difficult to determine the process when active transpiration is in progress. The water accumulates in the vessels only when transpiration is in abeyance. Sometimes it so happens that certain plants when cut, pruned, tapped or otherwise wounded, show a flow of sap from the cut ends or surfaces, quite often with considerable force. This phenomenon is commonly known as *bleeding*, and is often seen in many land plants in the spring, particularly grape vine, some palms, sugar maple, etc. Although the flow of sap is ordinarily slow, a considerable quantity of it exudes within a period of 24 hours in certain plants. Thus in some palms, when tapped there may be a flow of sap to the extent of 10-15 litres per day. The sap in such plants contains sugar in addition to organic and inorganic salts.

Conditions affecting Root Pressure. **(1) Temperature.** Temperature of the air as well as of the soil affects root pressure The warmer the air and the soil, the greater is the activity of the root. **(2) Oxygen.** There must be an adequate supply of oxygen to the roots in the soil for respiration; otherwise their activity diminishes and may soon come to a standstill. **(3) Moisture in** [illegible] moisture must be present in the soil. [illegible] the better. **(4) Salt in the soil.** Preponderance of salts, making the soil saline, greatly interferes with the absorption of water.

Transpiration

Plants absorb a la[illegible] hairs. Only a part [illegible] building-up proces[illegible] water vapour. Transpiration *is the giving off of water vapour from the internal tissue* [illegible] *the leaves, green s*[illegible] simple process of [illegible]

vity of the protoplasm and some structural peculiarities of the transpiring organs (see p. 267). A detached leaf is seen to lose water much more rapidly than the one still attached to the plant, and this loss has been found to be 5 or 6 times greater. The total quantity of water that evaporates from a single plant is considerable. It has been estimated that the loss of water from a single sunflower plant during a period of 144 days is 27,000 c.c. This means there is a daily average loss of 187.5 c.c **Mechanism of transpiration.** Water evaporates at all temperatures, and since the parenchymatous cells are charged with water, it continues to evaporate from these cells and collect in the intercellular spaces so long as these are not saturated with water vapour. From there the water vapour escapes into the atmosphere either through the stomata or through the thin cuticle. The former is called **stomatal transpiration**, and the latter **cuticular transpiration**. Stomatal transpiration is the rule, and is many times (approximately about ten times) in excess of cuticular transpiration under ordinary conditions of light, temperature and humidity. At night the stomata remain closed and transpiration is checked. Since water vapour is given off in transpiration, the process markedly affects the humidity of the air around. The air under big leafy trees is moist and cool for the same reason. In dorsiventral leaves the lower surface has always a much larger number of stomata; often none or sometimes comparatively few are present in the upper. Consequently this surface transpires water more vigorously than the upper. In isobilateral leaves, however, stomata are more or less evenly distributed on both the surfaces. The guard cells no doubt regulate transpiration to a considerable extent by partially or fully opening the stoma or by closing it altogether according to circumstances. But it cannot be said that transpiration always takes place at the maximum rate through fully-open stomata. As a matter of fact in some plants half-open stomata are as efficient as fully-open ones. Recent investigations have shown that the degree of stomatal opening cannot always be directly correlated with the intensity of transpiration. Even when stomata are fully open, transpiration is greatly influenced by the water vapour in the respiratory cavities and even intercellular spaces. In woody plants and in many fruits transpiration takes place through the lenticels (see FIG. II/71). These organs help transpiration as they always remain open, and the water vapour escapes through the loose mass of cells (i.e. the complementary cells) of each lenticel (**lenticellate transpiration**).

Experiment 11. Transpiration: bell-jar experiment. Transpiration can be easily demonstrated in the following way. A pot plant with its soil-surface covered properly with a sheet of oil-paper is enclosed in a bell-jar and maintained at room temperature for some time. It is then seen that the inner wall of the bell-jar becomes bedewed with moisture.

Experiment 12. Unequal transpiration from the two surfaces of a dorsiventral leaf

(FIG. 11). Soak small pieces of filter paper or thin blotting paper in 5% solution of cobalt chloride (or cobalt nitrate) and dry them over a flame. The property of cobalt papers is that they are deep blue when dried, but in contact with moisture they turn pink. Place two dried cobalt papers, one on the upper and the other on the lower surface of a thick, healthy leaf, and cover them completely with glass slides (or with a leaf-clasp, as shown in the figure), and clamp them properly to the leaf. Then quickly seal the sides with vaseline. It will be seen that the cobalt paper on the lower surface of the leaf turns pink sooner than the one on the upper surface. This change in coloration takes place within a few minutes. This evidently shows that the leaf transpires water more vigorously from the lower surface than from the upper. This is due to the occurrence of a large number of stomata on the lower surface, none or few being present on the upper.

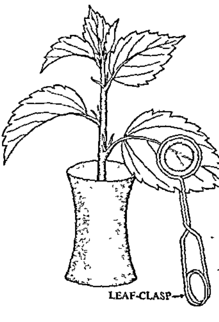


FIG. 11. Unequal transpiration from the two surfaces of a leaf.

Experiment 13. Quantitative estimation of unequal transpiration from the two surfaces of a dorsiventral leaf. (*a*) Fit up the apparatus (Garreau's potometer), as shown in FIG. 12. The two small test-tubes containing dehydrated calcium chloride are weighed before introducing them into the small bell-jars. The leaf is placed in between the two and the sides smeared with vaseline; other connexions are also made air-tight. The two bent tubes at the two ends are partially filled with oil. The experiment is carried out in bright light. After exposure for a few hours the test-tubes are re-weighed. The difference between the initial and final weights in each case will indicate the quantity of water absorbed by calcium chloride, evidently lost by transpiration from a unit area of the leaf within a specified time. It will be noted that the loss of water from the lower surface is much greater than that from the upper surface.

(*b*) Two long-stalked leaves of *Begonia*

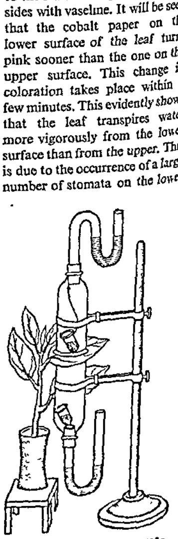


FIG. 12. Quantitative estimation of unequal transpiration with Garreau's potometer.

or garden nasturtium are taken and weighed separately. The upper surface of one leaf is coated with vaseline, while the lower surface of the other leaf is similarly coated. The two leaves are then exposed to sunlight for an hour or so. They are then separately re-weighed. The difference in weight will indicate in each case the quantity of water lost by transpiration Thus a comparative idea may be had of cuticular transpiration from the upper surface and stomatal transpiration from the lower surface of the leaves.

Experiment 14. Rate of transpiration under varying external conditions. Cut three healthy leafy twigs and immediately put each in a light-weight bottle or conical flask half-filled with water, and pour a few drops of olive oil to prevent evaporation of water. Take the weight of each and expose one to direct sunlight, another to subdued light and keep the third one in a dark room, each for a sepcified period, (say, two hours). Then take the weight of each again. The one exposed to sunlight will show the maximum rate, the second one much less, and the third one very little or no transpiration.

Experiment 15. Transpiration in relation to stomatal aperture. Proceed as in experiment 14 and then take a leaf from each. Peel off or slice off the epidermis and put it immediately into absolute alcohol to fix the stomatal aperture. Then by micrometric measurements find out the average width of at least ten stomata in each case, and correlate the width with the rate of transpiration.

Experiment 16. To find out the degree of stomatal opening with Darwin's porometer (FIG. 13). The porometer is an ingenious and interesting device which gives a comparative idea about the degree of stomatal opening under different external conditions. The small jar of the apparatus at the end of the rubber-tube is glued to the leaf-surface (a thick smooth isobilateral leaf of *Crinum* or *Amaryllis* will serve the purpose well), and the long arm of the T-tube dipped into mercury. With a suction pump fixed to the distal end of the other rubber-tube the mercury is lifted to a desired height in the long arm of the T-tube, and the rubber-tube is clipped. The experiment may be carried out in the morning, noon and evening (and also on a bright sunny day or a cloudy day). The rate of falling of the mercury-column within a specified time in each case indicates the degree of stomatal opening. Evidently when the stomata are fully open the mercury-column falls quickly, when only partially open the rate is slower, and when closed the column remains almost stationary.

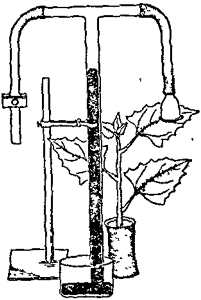


FIG. 13. Darwin's porometer (see experiment 16).

Experiment 17. Measurement of the rate of transpiration current (FIG. 14). This experiment is best carried out with the help of Ganong's potometer, as depicted

in the figure. The apparatus is filled with water, and a branch cut under water is inserted into the upper wide end of the apparatus through a cork, and the connexions made air-tight by applying paraffin-wax. The distal end of the apparatus

air to enter it. Dip it into water again. An air-bubble is seen to form at the

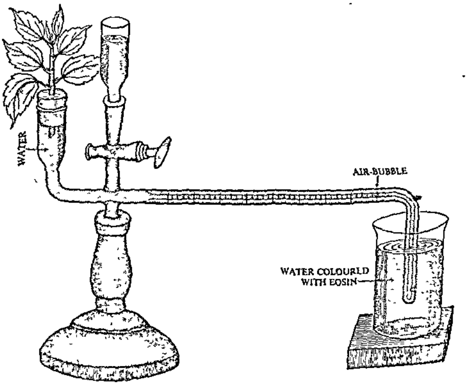


FIG. 14. Ganong's potometer to demonstrate the rate of transpiration current.

and the experiment re-started.

cork into the bottle which is filled with water. The level of water is noted in the side-tube, and 1 or 2 drops of oil poured into it to prevent evaporation of water from the exposed surface. The connexions are, of course, made air-tight. The whole apparatus is then weighed on a compression balance (FIG. 16) and the weight noted. It is seen after a time that the water-level has fallen, indicating the

volume of water that has already been absorbed by the plant. The apparatus is then re-weighed. The difference in weight evidently shows the amount of water that has transpired from the leaf-surfaces. If the experiment be continued for a period of 24 hours it will be seen that the volume of water (in c.c.) absorbed is

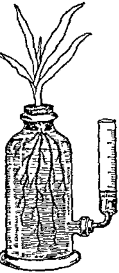


FIG. 15

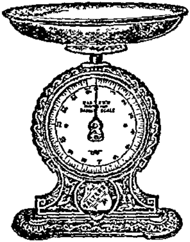


FIG. 16

FIG. 15. Relation between transpiration and absorption.

FIG. 16. Compression balance.

is almost equal to the amount of water (in grams) lost by transpiration (1 c.c. of water=1 gm.). In this way the relation between transpiration and absorption can be worked out for the various hours of the day and under diverse external conditions. It will be noted that the experiment also shows separately the 'rate of absorption' and the 'rate of transpiration'.

Experiment 19. Suction due to transpiration (FIG. 17). Take a manometer (i.e. the tube with a side arm, as shown in the figure) and fix to its lower end a long narrow glass tube. Completely fill the tubes with water and insert a leafy shoot, with the cut end kept under water, into one of the arms of the manometer through a rubber cork. Close the other end with a cork. Make all the connexions air-tight by applying melted paraffin-wax. Dip the lower end of the tube into mercury in a beaker. As transpiration goes on water is absorbed, and within a few hours mercury is seen to rise in the tube to some height. This rise of mercury indicates the suction exerted by transpiration. The physiological processes connected with this phenomenon are: (*a*) osmosis in the mesophyll cells by which water is withdrawn from the tracheids in the veinlets; (*b*) evaporation of water from the mesophyll cells through the leaf-surface, bringing about concentration of their cell-sap; and (*c*) transpiration pull exerted on the column of water in the long tube, resulting in its absorption into the branch and the rise of mercury in consequence.

Transpiration Ratio. The term transpiration ratio (sometimes called *transpiration coefficient*) is widely used to express the ratio between the total amount of water that transpires from the plant body during the growing season and the total amount of dry matter that accumulates in it during this period. Since the differ-

ence between the amount of water transpiring from a plant and that absorbed by it is not great, the term *water requirement* is also often used to express the ratio between the total amount of water absorbed by a plant and the total amount of dry matter formed in it at the end of the growing season. Thus the transpiration ratio or the water requirement represents the number of grams (or kilograms) of water that transpires (or is absorbed) to produce one gram (or kilogram) of dry matter. The ratio varies from plant to plant and also in the same plant under different conditions. The ratio has already been worked out for a number of crop plants and weeds. Values obtained for some of the common field crops are: 368 for maize, 513 for wheat, 636 for potato, 646 for cotton, 683 for sunflower, 831 for lucerne (or alfalfa), etc., meaning that to produce one gram of dry matter the above quantity of water (in gm or c.c.) has transpired (or has been absorbed) in each case.

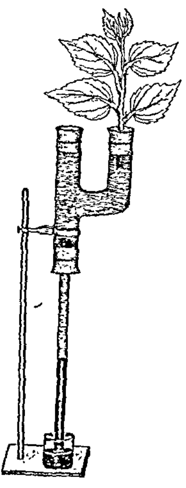


FIG. 17. Suction due to transpiration.

Importance of Transpiration. Transpiration is of vital importance to the plant in many ways. (1) In the first place we find that roots are continually absorbing water from the soil, and this water is several times in excess of the immediate requirement of the plant; the excess is got rid of by transpiration. (2) The rate of absorption of water is greatly influenced by the rate of transpiration. The greater the transpiration the greater is the rate of absorption of water from the soil. (3) Absorption of water helps the intake of raw food materials (inorganic salts) from the soil. It is, however, not a fact that the greater the transpiration the greater is the rate of absorption of inorganic salts from the soil. As a matter of fact the intake of salts is independent of the quantity of water absorbed. (4) Transpiration secures concentration of the cell-sap and thereby helps osmosis. (5) As a result of transpiration from the leaf-surface a suction force (see experiment 19) is generated which helps the ascent of water to the top of lofty trees. (6) Transpiration also helps the distribution of water

porates hygroscopic salts are left on the surface of the leaf. These salts absorb moisture from the atmosphere, and do not allow the leaf or the plant as a whole to dry up In the face of all these advantages the fact remains that excessive transpiration is a real danger to plant life. Many plants are often seen to dry up and die when *excessive transpiration takes place for a prolonged period.*

FACTORS WHICH AFFECT TRANSPIRATION

(1) **Light.** Light is the most important factor. Transpiration normally takes place in light and, therefore, during the daytime. This is due to the fact that in the presence of light stomata remain fully open and evaporation of water takes place normally through them. At night stomata remain closed and consequently transpiration (except for a little cuticular transpiration) is markedly checked. Variations in the intensity of light as on a bright day and a cloudy day *bring about different degrees of stomatal opening and so have a* marked effect on transpiration. During the daytime again heat-rays of the sun directly falling upon the leaves enhance to a great extent the rate of transpiration.

(2) **Humidity of the Air.** There is an increase or decrease in the rate of transpiration according as the air is dry or moist. When the atmosphere is very dry it receives moisture very readily, but when it becomes very moist or saturated it can receive no more water vapour. Loss of water by transpiration is then very slight. Even though the stomata remain open at daytime, transpiration is greatly influenced by water vapour in the air.

(3) **Temperature of the Air.** The higher the temperature, the greater is the transpiration; at high temperatures the water evaporates more freely than at low temperatures When the two factors, viz. dryness of the air and high temperature, combine transpiration is markedly enhanced.

(4) **Wind.** During high wind transpiration becomes very active because the water vapour is instantly removed and the area around the transpiring surface is not allowed to become saturated.

Adaptations to reduce excessive Transpiration. *Anatomical.* A thick cuticle and sometimes a multiple epidermis develop to check excessive evaporation of water. The loss of water from an apple with the cuticle removed is far greater than that from the one with the cuticle intact. The presence of cutinized hairs, scales, rods, etc., minimizes transpiration to a greater extent. A dense coating of hairs or of wax or 'bloom' on the surface is very efficient in this respect. Latex also checks transpiration. Stomata may be closed temporarily even in daytime when excessive transpiration is taking place from the leaf-surface. In desert plants stomata remain sunken in pits (see FIGS.

II/44-5), and these stomata are also very much reduced in number. After a time in shrubs and trees cork is formed to act as a waterproof covering and to afford protection of other kinds (see p. 223). Cork cells being suberized are impervious to water and, therefore, loss of water by transpiration is prevented. A peeled potato transpires more quickly than an unpeeled one. Later still in the life of these plants bark is formed as a hard, dry covering to carry on identical functions.

Morphological. The leaf-area is often very much reduced; in extreme cases leaves are modified into spines. The size of the plant is also often reduced. Leaves may be rolled up or variously folded exposing minimum surface for transpiration. They may also assume a drooping or vertical position to avoid strong sunlight. It is further seen that deciduous trees shed their leaves in winter as a protection against excessive transpiration, while evergreen trees have their leaves well covered with cuticle.

Exudation of Water. The excess of water is also got rid of in many herbaceous plants by a process, commonly called *exudation, or guttation.* Thus in balsam, rose, water lettuce, grape vine, many aroids (e g. taro), garden nasturtium, sunflower, *Chrysanthemum, Canna,* many grasses, etc., it is seen that drops of water accumulate at the apex or margin of the leaf in the early morning. The water has escaped through the water stomata (or water pores) and hydathodes that have developed in that region (see p. 179). That the water is not dew-drops is evident from the fact that the drops are regularly arranged at the ends of veins, and that chemical analysis shows the presence of organic and inorganic salts. Exudation normally takes place during a warm and damp night. In some plants a considerable quantity of water exudes every night. The cause of exudation is to be sought in the wall pressure (see p. 235) that develops in the fully turgid parenchymatous cells that lie in the adjoining parts. Conditions necessary for the process are: abundant supply of water, a suitable temperature and activity of the living cells of the root; and also other conditions which check transpiration. At very low temperatures practically no exudation takes place.

Experiment 20. Escape of water in liquid form from the leaf: guttation. Fix a branch of a plant (e g. balsam) to the short arm of a J-tube and apply paraffin-wax to the connexion to make it air-tight. Partially fill the J-tube with water leaving no air-gap between the water-column and the connexion. Then pour mercury into the long arm of the J-tube almost filling it. The excess water will flow out. The mercury-column will compress the water-column in the short arm and as a result it will be seen within a short time that drops of water have accumulated on the leaf-margin at the ends of veins.

Transpiration and Exudation. (1) In transpiration water escapes in the form of vapour; while in exudation water escapes in liquid form.

(2) The water that escapes in transpiration is pure; while the water that escapes in exudation contains minerals in solution.

(3) In transpiration water escapes through the stomata and to some extent through the cuticle; while in exudation water escapes through the hydathodes (see FIG. II/39) and water stomata (or water pores). Ordinary stomata are distributed all over the surface (commonly lower) of the leaf, while hydathodes and water stomata develop at the margin or apex of the leaf at the end of a vein.

(4) Transpiration is regulated by the movement of the guard cells, partially or wholly opening or closing the stomatal aperture; while exudation cannot be so regulated, the guard cells of the water stomata having lost the power of movement.

(5) Transpiration normally takes place in the presence of sunlight and, therefore, during the daytime; while exudation takes place in the absence of transpiration and, therefore, at night.

(6) Transpiration secures concentration of sap, and also keeps the plant cool by dissipating the excess heat absorbed from sunlight; exudation has no such effect.

Ascent of Sap

The water absorbed from the soil by the root-hairs is conducted upwards to the leaves and the growing regions of the stem and the branches. A cut branch of lupin bearing white flowers dipped into eosin solution shows a gradual change in the coloration of flowers from white to pink within a few minutes. In herbaceous plants the height this water has to reach is small, but in some trees such as *Eucalyptus*, some conifers, etc., which may attain a height of over 90m. or more, the distance to be traversed by this column of water is considerable, and the water has to resist a considerable pressure to reach that height. The rate at which the transpiration current flows upwards through the vessels varies a good deal in different plants, and at different times in the same plant. Generally speaking, the rate is about 1 to 2 metres per hour in healthy trees. Two questions naturally arise in this connexion: what is the path of movement of sap and what are the factors responsible for the ascent of sap?

Path of Movement of Sap. The path of movement of sap may be determined in one of the following two ways: (*a*) a small herbaceous plant (e.g. *Peperomia*) or a small branch of a plant (e.g. lupin) may be stood in eosin solution. After a short time sections, cross and longitudinal, are prepared from it at different heights and examined under the microscope. Sections will show the presence of coloured solution only in the vessels and tracheids. Therefore, these are the elements through which movement of sap, or transpiration current as it is called, takes place. (*b*) All the peripheral tissues right up to the phloem and cambium may be removed in the form of a

ring (girdling) from a branch, leaving the xylem intact. In a cut branch treated similarly the pith may also be crushed. It is seen that no wilting of leaves takes place. As it is only the xylem that remains intact we may conclude that ascent of sap takes place through it. This is known as a 'ringing' experiment.

Factors Responsible for the Ascent of Sap. Various theories have been advanced from time to time to explain the ascent of sap, but none has proved satisfactory yet. It is believed that root pressure forces up the water to a certain height, and that transpiration exerts a suction force on this column of water from above. In short, it may be said that root pressure gives a 'push' from below and transpiration a 'pull' from above. In this respect transpiration is a more powerful factor. Probable theories regarding the ascent of sap are as follows:

A. PHYSICAL THEORIES

(1) **Root Pressure.** Root pressure is regarded as one of the forces responsible for the ascent of sap. Many plants are seen to eject water with great force (bleeding) when the stem is cut above the ground. This phenomenon has been explained as due to the osmotic pressure which operates in the root-cortex to produce the root pressure. Root pressure may be adequate to force up water in herbs, shrubs and low trees, and that too in the absence of transpiration. Root pressure can hardly generate 2 atmospheres of pressure and a maximum height to which a column of water may be raised by this pressure is only about 19m.; whereas a pressure amounting to 10-20 atmospheres is required to send the sap to the top of lofty trees, sometimes 90m. or even more in height. Root pressure is thus inefficient in this respect. The process is also slow and cannot keep pace with the water lost by transpiration; further, root pressure is lowest when transpiration is highest; in fact, during active transpiration the water in the vessels is under a negative pressure. In many plants root pressure is absent or feeble at certain times of the year. Besides, water still rises through the stem if the roots are decapitated and the cut end of the stem dipped into water.

The role of root pressure in the ascent of sap has, however, been emphasized by White (1938). He has experimentally shown that excised tomato roots exude water with a pressure amounting to 6 atmospheres or even more. This pressure is sufficient to raise a column of water to a height of 54m. or even more.

(2) **Transpiration Pull and Force of Cohesion.** The understanding of the subject of ascent of sap was immensely advanced by the theory of Dixon and Jolly (1914), concerning the tensile strength of the water column in the vessels due to a strong force of attraction

(cohesion) between the water molecules, osmosis in the mesophyll cells of the leaf, and transpiration pull due to evaporation of water from the leaf-surface. According to the 'cohesion' theory the water molecules cohere together and form into a long continuous column in the vessels extending from the root to the leaf without air-bubbles anywhere. The water molecules cohere so strongly to one another that the column does not break or form bubbles anywhere in its entire length even under a state of very high tension due to transpiration pull, as further proved by Bode in 1923 by his microscopic observations of *Cucurbita, Impatiens, Tradescantia*, etc. Even if the water column breaks, its continuity is maintained by the vapour phase. The cohesive power of water, as has been experimentally proved by them, may maintain a very long column of water under tension greater than 100 atmospheres of pressure. Apparently the water column behaves as a solid column. It is to be noted that only a tension of 10 atmospheres, possibly 20 atmospheres considering the frictional resistance of the walls, is required for the ascent of sap to a height of 104m. The next operative factor is osmosis. It has been estimated that osmotically active mesophyll cells can draw up water from the ends of vessels against a pressure of 10-20 atmospheres. Finally transpiration plays its part as a powerful factor. A strong suction force, as already proved by Askenasy in 1880, is generated as a result of transpiration from the leaves. Evidently a pull is exerted on the end of the water-column, and the whole column is bodily pulled up like an iron rod which can be lifted by one hand.

(3) **Capillarity.** The level of water inside a capillary tube is always higher than the level outside; the smaller the bore of the tube, the higher will be the rise of water in it. Xylem vessels may be regarded as so many capillary tubes extending from the root to the leaf, but from the known diameter of the vessels it is obvious that the rise of water can hardly exceed a metre or so. Further, the conducting elements in gymnosperms are so many tracheids with numerous transverse septa (and not vessels). Capillarity again implies free surface, but this is not found in plants as the vessels end in parenchymatous cells, and the water in the vessels is not in direct communication with the soil-water.

(4) **Imbibition Theory.** Sachs (1874) suggested that water moves along the walls of xylem vessels (and not through their cavities) due to the imbibition force (see p. 232), and this is responsible for the ascent of sap in plants. But when the cavities of the vessels are artificially blocked with oil, air or gelatin the branches are seen to wilt showing thereby that the amount of water absorbed by this process cannot at all keep pace with the amount of water lost by transpiration. The force of imbibition is no doubt great but the movement of water by this process is slow.

B. VITAL THEORIES

(1) **Vital Force.** Activity of living cells, e.g. wood parenchyma and medullary ray cells surrounding xylem, has been held by Godlewski (1884) to be responsible for the rise of sap through the plant body. The role played by the living cells is like that of relay pumps. The living cells take water from the vessels at a particular level and then force it again into the vessels at a higher level, and the sap thus rises. Strasburger (1891), however, refuted the idea of vital force by killing the living cells by the application of heat as well as by poisonous chemicals. He was definite that the forces concerned are physical rather than physiological. The vessels of the root no doubt withdraw water from the adjoining living cells.

(2). **Pulsation Theory.** According to the late Sir J. C. Bose (1923) the ascent of sap is due to active *pulsation* of the internal layer of the cortex abutting upon the endodermis. This he proved with the help of a fine electric probe which was thrust into the stem layer by layer; the probe was connected with a galvanometer. When it reached that particular layer the pulsating activity was suddenly exhibited; on either side of the layer the activity suddenly disappeared. His conclusion was that due to the pulsating activity of the living cells of this layer a sort of pumping action is set up, and this is responsible for the *physiological* propulsion of the sap upwards through the stem. Conduction of water takes place through this layer even in the absence of root pressure and transpiration. Xylem vessels being dead and inactive no pulsation is exhibited by them, and these were regarded by him as only reservoirs of water; mechanical transport of water according to him is only possible through them to some extent. The cortex injects water into them and withdraws it from them according to circumstances. All the living cells exhibit pulsation to a greater or less extent, but the activity of the internal cortex is exceptionally great. Anatomical and experimental evidence, however, does not support this view.

Chapter 6 MANUFACTURE OF FOOD

I. CARBOHYDRATES

Photosynthesis (the name first proposed by Barnes in 1898). *Photosynthesis* (*photo*, light; *synthesis*, building up) *consists in the building*

up of simple carbohydrates such as sugars in the green leaf by the chloroplasts in the presence of sunlight (as a source of energy) from carbon dioxide and water absorbed from the air and the soil respectively. The consensus of opinion is that glucose is formed first and all other carbohydrates are derived from it. The process is accompanied by a liberation of oxygen (see experiment 21). The volume of oxygen liberated has been found to be equal to the volume of carbon dioxide absorbed. But it is to be noted that all the oxygen liberated in the process is released exclusively from water (H_2O) and not from carbon dioxide (CO_2). Oxygen escapes from the plant body through the stomata. This formation of carbohydrates, commonly called **carbon-assimilation**, is the monopoly of green plants only, chlorophyll being indispensable for the process. By this process not only are simple carbohydrates formed but also a considerable amount of *energy* (initially obtained from sunlight as radiant energy) is transformed by green cells into chemical energy and stored up as such in organic substances formed. It must be noted that photosynthesis takes place only in the green cells and, therefore, mainly in the leaf and to some extent also in the green shoot. Under favourable conditions of light intensity and temperature the rate of photosynthesis increases enormously and a tremendous amount of CO_2 is absorbed from the air for this process, so much so that on a windless day the CO_4 content of the air over a field crop may drop to 0.01% from normal 0.03%.

Mechanism of Photosynthesis.[1] Photosynthesis is the biological process by which some energy-rich carbon-containing compounds are produced from carbon dioxide and water by the *illuminated* green cells, liberating oxygen as the by-product. It is essentially an oxidation-reduction[2] process by which hydrogen is transferred from water to carbon dioxide through a 'carrier' substance, the nature of which is still imperfectly understood. In the process the volume of CO_2 absorbed is almost equal to that of O_2 liberated in most green plants (Boussingault, 1864). Since glucose appears to be the first carbohydrate formed in photosynthesis the over-all reaction may be represented thus: $6CO_2 + 12H_2O \longrightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$. This over-all reaction does not, however, explain the sequence of reactions involved in the process. It is not a single and simple reaction between CO_2 and H_2O to produce the end-product but a very highly complex and self-multiplying process in which a number of reac-

[1] Mainly based on *Plant Physiology* by Thomas, 'The Mechanism of Photosynthesis' by Fogg (*New Biology 11*) and 'Carbon Dioxide Fixation by Green Plants' by Benson and Calvin (*Annual Review—Plant Physiology I*, 1950), and *Principles of Plant Physiology* by Bonner and Galston.

[2] Oxidation means (*a*) addition of oxygen or (*b*) removal of hydrogen. Reduction means (*a*) addition of hydrogen or (*b*) removal of oxygen.

tions, of both a chemical and photo-chemical nature (some at least being enzymic) occur. The complexity is further increased by the fact that in this pro
takes place, i.e. the
is transformed into
available for all vita
synthetic mech
however, been
phyll, splitting
production of a reducing agent for the reduction and fixation of carbon dioxide, formation of a detectable quantity of phosphoglyceric acid as a stable intermediate compound, and finally its conversion into carbohydrates, as described below.

Nature of Reactions. Photosynthesis as a whole fundamentally consists of an oxidation-reduction series, in which one compound is oxidized (hydrogen transferred or donated) at the expense of the other which is reduced (hydrogen added or accepted). This may be represented by the following symbols:

A (H-acceptor) + BH_2 (H-donor) $\rightarrow$ AH_2 (reduced acceptor) + B (oxidized donor)

A and B may represent a number of substances. In photosynthesis, however, water acts as the hydrogen-donor (BH_2) and carbon dioxide as the hydrogen-acceptor (A). Plant physiologists soon came to realize that the production of carbohydrates from H_2O and CO_2 consists of two types of reactions—one for which light is essential

and the reduction of carbon dioxide to organic compounds by a reducing agent; as a matter of fact all the reactions from CO_2-reduction to final product formed are dark reactions. For continuity of the process, however, some product of light reaction is essential. By the use of light in flashes (intermittent light) Warburg in 1919 showed that in photosynthesis at least three dark reactions (*Blackman reaction*) participate. The existence of linked light and dark reactions in photosynthesis has been further proved by later workers (Emerson and Arnold in 1932, Briggs in 1935, and others in 1951-2).

Role played by Light and Chlorophyll. Light, as is well known, is an essential condition for the process of photosynthesis. The part played by it in any photo-chemical reaction is not, however, completely understood, and consequently a clear and complete explanation of the action of light in photosynthesis cannot be given. Suffice it to say that *radiant* energy absorbed by chlorophyll is transformed into

chemical energy which is effective in the splitting of water (see photolysis below). It may be noted that ordinarily green plants do not evolve O_2 in the absence of CO_2, even if they are illuminated. But experiments carried out by Hill in 1937 have proved that a considerable quantity of O_2 may be evolved by illuminated green cells provided that a hydrogen-acceptor such as certain ferric salts, or benzoquinone be available as a substitute for CO_2. The energy required for CO_2 transformation is the potential chemical energy stored in green cells. It has been estimated that an average green leaf absorbs about 80-85% of light; in photosynthesis, however, only about 1% of light is utilized. A portion of light may be reflected from the leaf-surface and from the chloroplasts, a portion is lost in heat, and another portion is used in transpiration. Experiments have proved that only certain rays (not all) of light are used for photosynthesis (see pp. 286-7).

Chlorophyll is indispensable for photosynthesis. It is, however, not known what exact role it plays in the process excepting that (*a*) it absorbs radiant energy in a selective manner (see pp. 286-7) and possibly also transfers this energy, partly at least, to the photosynthetic products; it is, however, not clear how the absorbed energy is effective in the process of decomposition of CO_2; and (*b*) chlorophyll plays the part of a *sensitizer*; the action is catalytic because neither the amount of chlorophyll in a leaf nor the constituent pigments are seen to be altered by a prolonged period of photosynthesis. Chlorophyll does not enter into any reaction with carbon dioxide.

Photolysis of Water. The initial and essential part of photosynthesis lies in photolysis of water, i.e. splitting of water molecules; this is essentially a light reaction taking place in the body of the chloroplast. It is in this reaction that the conversion of radiant energy into potential chemical energy occurs. The site of CO_2 fixation and reduction in the cell is not, however, definitely known. In the chloroplast the chlorophyll is intimately associated with molecules of fatty substances and proteins in the form of large and complex molecules. The absorbed light energy may produce a chemical change anywhere within this complex and may even alter the properties of chlorophyll. Whatever be the nature of alteration, if any at all, physical or chemical, chlorophyll soon returns to its normal condition. The final effect is, however, the splitting of water molecule into two highly reactive components. This may be represented by the following type of reaction:

$$H_2O + Z \xrightarrow{\text{light}} \underset{\text{oxidized}}{(OH)} + \underset{\text{reduced}}{HZ}$$

Z represents chlorophyll, chlorophyll complex or a hydrogen-acceptor (some substance deriving chemical energy from chloro-

phyll). In normal photosynthesis water is the specific hydrogen-donor. Here the water, a substance of low potential chemical energy, is split up under the influence of light energy and catalytic action of chlorophyll into two highly reactive components. One component, HZ, formed by combination of hydrogen with some substance of the chlorophyll complex (the identity of which is not yet established) is a reduced compound of high potential chemical energy. The reduced compound, HZ (whatever be its nature), is now available for reduction and fixation of carbon dioxide in dark reactions, finally leading to the formation of sugar. In the absence of this reducing agent photosynthesis cannot proceed further. The other component, (OH), of water forms peroxide which subsequently decomposes liberating O_2 in molecular form—$2(OH)\rightarrow H_2O_2$; $2H_2O_2 \longrightarrow 2H_2O+O_2$.

Hill Reaction. Hill in 1937 and 1939 showed that the production of O_2 may occur in the complete absence of CO_2 provided that a hydrogen-acceptor is available. The identity of this substance is no doubt very important but it is believed to be already present in the green cells. Hill used ferric oxalate and found that isolated chloroplasts in water, when illuminated, without the presence of CO_2, produced O_2. Other compounds like ferricyanides, chromates and quinones (e.g. benzoquinone) have been used with similar results. Hill reaction may be represented by the following equation:

$$2H_2O+2A \xrightarrow[\text{chloroplasts}]{\text{light}} 2AH_2+O_2$$

In this equation A represents a hydrogen-acceptor (whatever be its nature). It is evident from the equation that all the oxygen released in the process comes solely from water (and not from carbon dioxide as hitherto believed). Hill reaction is essentially the splitting of water under the influence of light energy with the release of O_2 [illegible] corroborated by Ruben and others (1941 and 1943) by using radio-active oxygen, O^{18} in water, H_2O^{18}. It is thus conclusively proved that all the oxygen released in photosynthesis comes exclusively from water.

Fixation of Carbon dioxide. Smith in 1943 showed that nearly the whole of carbon (a [illegible] traced in sugar an[illegible] recent years it has [illegible] particularly radioactive carbon, C^{14}, in carbon dioxide, i.e. [illegible] to trace to some extent at least the sequence of reactions through which the 'marked' C^{14} passes on its way to the final products

finally fructose or glucose appears in a free state. Later still 'marked' C^{14} appears in sucrose and starch. It may be noted that phosphoglyceric acid holds a pivotal position from which carbohydrates are formed in one direction following the main pathway of CO_2 fixation in photosynthesis, while in other directions phosphopyruvic acid, pyruvic acid, many stable organic acids, later amino acids (particularly alanine and aspartic acid) and finally proteins and also fats are elaborated. All the above reactions are reversible.

in the whole series of reactions. In the breakdown of sugar in respiration to phosphoglyceric acid and finally to CO_2 the role of enzymes as intermediate 'carriers' of hydrogen is more or less well known. It is probable that in photosynthesis, a process reverse to respiration, at least some of these enzymes (e.g. DPN,[1] TPN,[2] cytochromes, dehydrogenases, vitamin K, etc.) play a definite role. They have been found in green cells although not in the chloroplasts in all cases. It is possible other enzymes are also involved.

Role of Enzymes. Recent work has shown that a number of enzymes of the oxidation-reduction group play a definite part in photosynthetic metabolism both in light and dark reactions. They have been detected in green cells, and in some cases the enzyme reactions have been proved *in vitro*. It has been suggested that chlorophyll acts as a primary hydrogen-acceptor on photolysis of water,

is controlled by the activity of the enzyme hydrogenase. The reduction of CO_2 (i.e. addition of hydrogen) proceeds in a series of reactions provided that a reducing agent (hypothetically shown as HZ, see p. 275) already present in the green cells be available for the purpose. Dehydrogenases take part in transferring hydrogen from hydrogen-donor to hydrogen-acceptor. Cytochromes act as intermediate 'carriers' of hydrogen in stepwise reactions in the fixation of CO_2. Carboxylases are evidently concerned in incorporating reduced CO_2 into the carboxyl group (COOH) of phosphoglyceric acid. The influence of the following enzymes in the reduction series may be specially noted. Thioctic acid and vitamin K found in green cells may act as primary hydrogen-acceptors, subsequently transferring the hydrogen to DPN and TPN. Thioctic acid and vitamin K may also be the seats of conversion of radiant energy into potential chemical energy. DPN and T
and TPNH, being o
least to some extent.
rich phosphate compound ATP (adenosine triphosphate). ATP is also con-

[1] DPN—diphosphopyridine nucleotide. [2] TPN—triphosphopyridine nucleotide.

with water. It is better to cut the stems and tie up the shoots into a bundle. The cut ends should be projected upwards into the funnel. *Observation.* When exposed to bright light a stream of small gas bubbles is seen to rise upwards through the cut ends of stems and collect at the upper end of the test-tube, displacing the water. *Inference.* That the gas is oxygen can be proved in the following way. Close the test-tube with the thumb under water, and invert it over a dish containing a quantity of pyrogallate of potash (5% pyrogallic acid to which an excess of caustic potash has been added). Then with the help of a bent tube introduce into the test-tube a quantity of this solution. The pyrogallate solution coming in contact with the gas will absorb it and will, therefore, rise and completely fill up the test-tube. The pyrogallate solution absorbs oxygen. The gas in the tube is, therefore, oxygen.

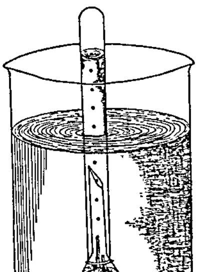


FIG. 18. Evolution of oxygen bubbles in photosynthesis of submerged water plants (*Hydrilla*).

Experiment 22. Analysis of gases with Ganong's photosynthometer. To analyse the gases—CO_2 and O_2—and to find out their quotient this instrument is very suitable. First fill up the graduated tube with water and then introduce into it a known volume of CO_2 from a generator by displacing water. Enclose a green leaf in the bulb of the photosynthometer, arrange the whole apparatus as shown in the figure, and expose it to bright sunlight for a few hours. Remove the graduated tube to a cylinder containing KOH solution. Note the rise of the solution in the tube indicating the volume of CO_2 still remaining unused. The total volume of CO_2 being known, the actual volume of CO_2 absorbed by the leaf can be easily calculated. Then transfer the graduated tube to pyrogallate of potash and note further rise of the solution in it. This will indicate the total volume of O_2 now present in the tube. The original volume of oxygen being known, the volume of O_2 given out by the leaf can be easily calculated. It will be noted that the two volumes almost maintain a quotient of unity.

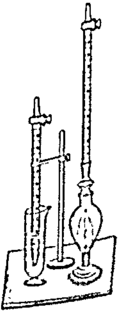


FIG. 19. Ganong's photosynthometer (see experiment 22)

Experiment 23. Photosynthesis: to demonstrate that starch is formed in photosynthesis (FIG. 20-2) Select a healthy green leaf of a plant [illegible]

portion of it on both sides with two uniform pieces of black paper, fixed in position with two paper clips or soft wooden clips, either in the morning before the sun rises or the previous evening, so that the experiment is performed with a starch-free leaf. Or, keep a healthy, green pot plant in a dark room for 1 or 2 days so that its leaves become starch-free, and then cover a portion of a leaf of this plant as described above. To make sure that there is no starch, collect a few neighbouring leaves in the morning, decolorize them with alcohol and dip them into iodine solution. It will be seen that they do not turn black. Evidently all the leaves are starch-free. Now let the plant be exposed to light for some time, preferably till the evening. Then collect the leaf, decolorize it with alcohol, and test it with iodine solution for starch grains. It will be seen that only the exposed portions turn blue or black.

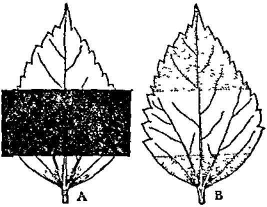


FIG. 20. Formation of starch grains in photosynthesis of land plants. A, leaf partially covered with black paper; B, covered portion without starch grains, while uncovered portions with plenty of them.

A very interesting experiment known as the starch print (FIG. 21) may be carried out in the following way. A stencil (which may be a blackened thin tin plate or a black paper) with the letters S T A R C H punched or cut in it is

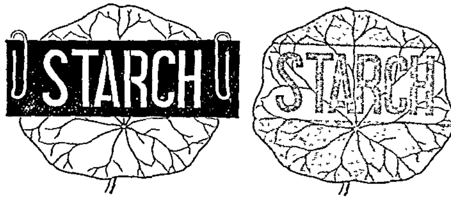


FIG. 21. Starch print in photosynthesis.

used for this purpose, the procedure being the same as described under the above experiment. Later, when the leaf is decolorized and treated with iodine solution, the print of S T A R C H will stand out boldly in black on the bleached leaf owing to the formation of starch grains with the access of light and their turning black in contact with iodine solution.

Instead of loose black paper or stencil a light-screen (FIG. 22) may be used to cover a portion of the leaf. The advantage of the light-screen is that it allows free ventilation and at the same time cuts off all light.

Experiment 24. *To find out the quantity of photosynthate in the given area of a leaf.* (*a*) Cover a selected number of symmetrical leaves with black paper or

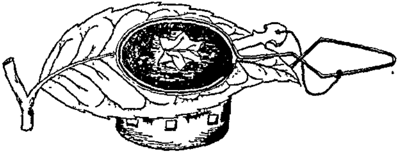


FIG. 22. A light-screen.

black cloth the previous day to make them starch-free. Cut out one-half of each leaf very close to the mid-rib and place the cut-out halves on a graph paper to find out their area as correctly as possible. Then expose the plant with the remaining halves to bright sunlight for some hours. Cut out those halves again very close to the mid-rib. Kill and dry both sets of half-leaves to get rid of all water, and weigh them separately. The difference in weight will indicate the quantity of photosynthetic products formed in the given area of leaves within a specified period.

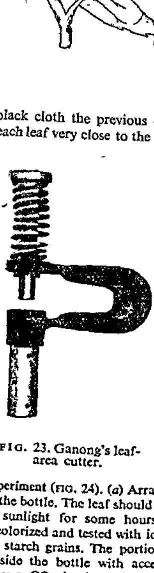


FIG. 23. Ganong's leaf-area cutter.

(*b*) C [illegible] With [illegible] rately and find out the weight in each case. The increased weight in the latter set will indicate the quantity of photosynthate formed in a given area within a specified period.

Experiment 25. *To show that plants cannot photosynthesize unless carbon dioxide is available:* **Moll's experiment** (FIG. 24). (*a*) Arrange, as shown in FIG. 24, with some KOH solution in the bottle. The leaf should be starch-free (see experiment 23). After exposure to sunlight for some hours the leaf is decolorized and tested with iodine solution for starch grains. The portion of the leaf outside the bottle with access of atmospheric CO_2 is the only part that turns black. A branch or a pot plant, starch-freed, may be used instead of a single leaf.

FIG. 24. Moll's experiment on photosynthesis. (The bottle contains some KOH solution).

(*b*) *Cover a healthy green pot plant, starch-freed, with a bell-jar stood on a large flat dish containing mercury (or distilled*

or even more, carbohydrate formation greatly increases (see limiting factors below).

(3) **Temperature.** Photosynthesis takes place within a wide range of temperature. It goes on even when the temperature is below the freezing point of water; but the maximum temperature lies somewhere at 45°C. The optimum temperature, i.e. the most favourable temperature for photosynthesis, may be stated to be 35°C. Both maximum and optimum temperatures, however, vary in different species of plants and in those growing under different climatic conditions.

(4) **Chlorophyll.** This is essential for photosynthesis; the plastids are powerless in this respect without the presence of chlorophyll. For the same reason non-green parts of plants cannot photosynthesize (see experiment 26). Fungi and saprophytic and parasitic phanerogams have altogether lost this power, being devoid of chlorophyll.

(5) **Potassium.** Potassium helps synthesis of carbohydrates and, therefore, in the absence of potassium salts starch grains are not formed. Potassium does not enter into the composition of carbohydrates but acts as a catalyst helping in their synthesis.

(6) **Water.** Water is indispensable for photosynthesis because water and carbon dioxide undergo chemical changes leading to the formation of carbohydrates under the influence of chloroplasts and in the presence of sunlight. It is, however, a fact that less than 1 per cent of the water absorbed by the roots is utilized in photosynthesis. Besides, water makes the photosynthetic cells turgid and active.

Limiting Factors in Photosynthesis. The principle of limiting factors was enunciated by Blackman in 1905. He showed that light intensity, carbon dioxide concentration and temperature are the limiting factors in photosynthesis, i.e. the ultimate rate of photosynthesis is determined by each such factor. Just as the strength of a chain is determined by its weakest link, so the rate of photosynthesis is controlled and limited by the least favourable factor. Under the normal condition of 0.03% concentration of CO_2 in the air and within a certain range of temperature photosynthesis may start with low intensity of light. Supposing then that the concentration of carbon dioxide remains constant, with increasing light intensity the rate of photosynthesis steadily increases until a particular maximum is reached. Without further increase in CO_2 concentration the rate of photosynthesis shows no further progress even if the light intensity is increased. It is evident then that at this point carbon dioxide acts as a limiting factor. Supposing again that light intensity remains constant it is seen that with increasing supply of CO_2, say from 0.03% to 0.5-1% or even more, the rate of photosynthesis will rise

again up to a certain point. Further increase in CO_2 concentration under the same condition of light intensity will have no influence on the rate of photosynthesis. At this point light acts as a limiting factor. Different concentrations of CO_2 are correlated with different intensities of light i.e. more intense light is required to utilize more concentrated carbon dioxide. But then there is a limit beyond which each factor inhibits the rate and may even check the process altogether. Within a certain range the effect of temperature on the rate of photosynthesis shows very little variation. But it has been noted that with low intensity of light, even if the concentration of CO_2 be high, the rate of photosynthesis does not appreciably increase with increase in temperature. With high light intensity, however, even if the CO_2 concentration be low, the rate of photosynthesis increases with increasing temperature until a particular point is reached.

Conditions necessary for the Formation of Chlorophyll. A number of factors, both internal and external, are responsible for the formation of chlorophyll. In the absence of any of them chlorophyll synthesis is in abeyance.

(1) **Light.** Normally chlorophyll does not develop in most plants in the absence of light, and continued absence of light also decomposes it into protochlorophyll (see p. 139). But in many algae, mosses, ferns and in the seedlings of many conifers and certain angiosperms chlorophyll may develop in the dark and the plants become green in colour. With the access of light, however, more chlorophyll develops in them and the plants become deeper green in colour. In most cases a low intensity of light is quite effective in inducing chlorophyll formation. It may also be noted that very strong light decomposes chlorophyll, particularly in shade-loving plants.

(2) **Temperature.** Chlorophyll develops within a wide range of temperature, the maximum rate usually varying from 26-30°C.; very high temperature, 45-48°C., decomposes chlorophyll.

(3) **Iron and Magnesium.** In the absence of the salts of these metals chlorophyll is not formed, and seedlings assume a sickly yellow appearance. In this condition they are said to be *chlorotic*. Although both iron and magnesium are required for the formation of chlorophyll it is only magnesium that enters into its composition.

(4) **Manganese.** It is also believed that manganese is necessary, even essential, for the formation of chlorophyll.

(5) **Nitrogen.** Nitrogen enters into the composition of chlorophyll and, therefore, in its absence chlorophyll fails to develop.

(6) **Water.** Leaves, when drying up in the absence of water, are seen to lose their green colour. Desiccation thus brings about decomposition of chlorophyll. In prolonged droughts leaves of many plants, particularly of grasses, turn brownish in colour.

(7) **Oxygen.** It is also necessary for the formation of chlorophyll.

Seedlings fail to develop chlorophyll in the absence of oxygen, even when these are exposed to sunlight. Chlorophyll formation is, therefore, an oxidation process.

(8) **Carbohydrates.** Cane-sugar, grape-sugar, etc., are also necessary for the formation of chlorophyll. Etiolated leaves without soluble carbohydrates in them, develop chlorophyll and turn green in colour when floated on sugar solution.

(9) **Heredity.** This is a powerful factor and determines the formation of chlorophyll in the offsprings. Familiar examples are garden crotons, aloes, maize, aroids (e.g. *Caladium*), amaranth, etc.

Chemistry of Chlorophyll. Chlorophyll, as it exists in the chloroplasts, is a mixture of four different pigments, as given below.

1 Chlorophyll *a*, $C_{55}H_{72}O_5N_4Mg$—a blue-black micro-crystalline solid.
2 Chlorophyll *b*, $C_{55}H_{70}O_6N_4Mg$—a green-black micro-crystalline solid.
3 Carotene, $C_{40}H_{56}$—an orange-red crystalline solid.
4 Xanthophyll, $C_{40}H_{56}O_2$—a yellow crystalline solid.

Extraction of Chlorophyll and Separation of Pigments. Pieces of green leaves (preferably grass leaves) are bruised in a mortar with sand particles and transferred to a flask with about 100 c.c. of 80% acetone. The flask is shaken for a few minutes and then allowed to stand. Acetone takes up all the colour (deep green) which is the[illegible]
fluorescence (see p. [illegible]
ether and methyl alc[illegible]
and allowed to settle. Within 2 or 3 minutes the solution separates out into two distinct layers—the upper (call it *A*) being deep green (containing chlorophyll *a* and carotene—both soluble in petroleum ether), and the lower (call it *B*) light greenish yellow (containing chlorophyll *b* and xanthophyll—both soluble in methyl alcohol). From the separating funnel the liquid *B* is collected in a test-tube, leaving the liquid *A* intact in the funnel. KOH solution and methyl alcohol are added separately to both the liquids (*A* and *B*) which are then shaken for a few minutes. The two liquids are then allowed to settle.

[illegible]

test-tubes. The nature of each pigment may be verified by spectrum analysis.

Effect of Rays of Light on Photosynthesis. It is a known fact that white light is composed of seven colours arranged in the following order: red, orange, yellow, green, blue, indigo and violet. Although photosynthesis normally takes place in white light, it is only a few of the above rays that are required for this function. [illegible]

to some extent only the orange ray. Green and other rays are not utilized to any extent (see experiments 27*a-c*).

Experiment 27. To find out the rays of light utilized in photosynthesis. (*a*) By covering a green starch-free pot plant with a double-walled bell-jar which is filled at a time with a red solution (aniline red), orange-yellow solution (potassium dichromate), blue solution (copper sulphate and ammonia; this transmits blue and violet rays), or green solution (ammoniacal copper sulphate and potassium dichromate), and exposing the same to bright sunlight for some hours the leaves may be tested for starch grains. The intensity of black colour which is the effect of iodine treatment gives a comparative idea about the quantity of starch formed in different rays. In the case of water plants the similar effect of rays of light may be studied from the rate of evolution of oxygen bubbles.

(*b*) **Ganong's light-screen (large form).** The proper use of this instrument gives a good idea about the rays of light utilized in photosynthesis. Of the five vials in it four are filled each with red, orange, green and blue solution, and the fifth vial with water. A starch-free broad green leaf of a plant is inserted through the hole of the light-screen to lie flat underneath the five vials. Evidently different rays of light will fall on the leaf in strips. After exposure to sunlight for some hours the leaf is bleached and treated with iodine solution. The intensity of coloration will indicate which rays have been utilized for photosynthesis.

(*c*) **Spectrum analysis of chlorophyll solution.** A direct-vision spectroscope may be used for this purpose. The spectrum analysis will show a broad dark band in the region of red, another in blue-violet, but only a small one in orange. Therefore, these are the rays mainly utilized by chlorophyll for photosynthesis.

II. PROTEINS

Nature of Proteins. These are very complex organic nitrogenous compounds found in plants. Analyses of protéins show that carbon, hydrogen, oxygen, nitrogen, sulphur and often phosphorus enter into their composition, but we know little about their molecular structure. Protein molecules are very large and extremely complex consisting of hundreds or thousands of atoms and are composed of several chains of amino-acid molecules. Besides these essential elements, small quantities of sodium, potassium, magnesium and iron are also present. Various kinds of proteins are found in plants. Most of them are very complex in their chemical composition. Amines and amino-acids are the initial stages in the formation of proteins, and they are also the decomposition products of the latter.

Synthesis of Proteins. Proteins are normally formed from nitrates absorbed from the soil. But the chemical reactions leading to the formation of these complex compounds are only imperfectly known. It has been already mentioned that phosphoglyceric acid holds a central position from which chains of reactions start—one leading to the formation of carbohydrates, while others to various organic acids, fats and proteins through phosphopyruvic acid, as revealed by radioactive carbon. It is likely that synthesis of the various products mentioned above proceeds simultaneously in different directions. Protein synthesis mostly takes place in the meristematic and storage tissues; some proteins are also formed in all active cells of

the plant body. It is believed that the whole process of protein synthesis takes place in three different stages. (*a*) Reduction of Nitrates. Nitrates, after they are absorbed into the plant body, are first reduced to nitrites, and the nitrites are further reduced to ammonia (amino group, $-NH_2$), as follows: $-NO_3 \longrightarrow -NO_2 \longrightarrow -NH_2$. This reduction takes place either in the root or in the leaf. (*b*) Synthesis of Amino-acids. This ammonia (amino group, $-NH_2$) then combines with sugar or some intermediate products of carbohydrate metabolism (photosynthesis and respiration), which supply the necessary carbon, hydrogen and oxygen in the building up of amino-acids. It is now known by the use of radioactive carbon that amino-acids are formed by the addition of amino group, $-NH_2$, to particular organic acids such as pyruvic acid and oxalacetic acid which are derived from phosphoglyceric acid during photosynthesis and respiration, and amino-acids like alanine and aspartic acid readily appear from them. The amino-acid, cystine, which is formed in all plants, also contains sulphur. There are over 20 different amino-acids known to be constituents of plant proteins. Amino-acids are mainly formed in leaves and stem-tips. (*c*) Synthesis of Proteins. Protein molecules are very large and complex. A protein molecule may be finally formed by linkage of hundreds or thousands of amino-acid molecules which may be arranged in the protein molecule in practically an infinite variety of ways. Emil Fischer first suggested (1899-1906) that proteins are formed by condensation of numerous amino-acids under the action of some enzymes. He mentioned 18 such amino-acids. As the hydrolysing enzymes break down proteins into amino-acids during the germination of seeds, in the reverse way these enzymes condense back the amino-acids into proteins. Complex proteins contain sulphur and phosphorus also. These elements are supplied by sulphates and phosphates obtained from the soil. In some plants amino-acids are mainly formed in the roots. They travel from there to distant tissues, and protein synthesis mostly occurs in the meristematic and storage tissues. Proteins, however, do not travel as such.

III. FATS AND OILS

The different stages in the formation of fats and oils are only imperfectly known. They are synthesized from glycerine and fatty acids under the action of the enzyme *lipase*. Both glycerine and fatty acids may be derived from some intermediate products of carbohydrates (particularly glucose and fructose) formed as a result of metabolic breakdown during respiration. Recent work has shown that fatty acids may be formed from phosphopyruvic acid as a chain of reactions in photosynthesis. The process is independent of light and chlorophyll. (See also pp. 153-4).

Chapter 7 SPECIAL MODES OF NUTRITION

Green plants are autotrophic (*autos*, self; *trophe*, food) or self-nourishing, that is, they are able to manufacture carbohydrates from raw or inorganic materials and thus nourish themselves. Non-green plants on the other hand are **heterotrophic** (*heteros*, different). Such plants cannot prepare carbohydrates and nourish themselves. They get their supply of carbohydrate food from different sources. They can, however, prepare other kinds of food. Heterotrophic plants are parasites when they depend on other living plants or animals, and they are saprophytes when they depend on the organic material present in the soil or in the dead bodies of plants and animals.

1. **Parasites** (see pp. 16-18). Total parasites such as dodder (*Cuscuta*), broomrape (*Orobanche*), etc., are never green, and consequently they have no power to prepare their own food. They draw in all their nourishment from the host plant on which they are parasitic. Partial parasites like mistletoe (*Viscum*), *Loranthus*, *Cassytha*, etc., on the other hand, are green in colour and are, therefore, not entirely dependent on the host plant. Parasitic phanerogams develop haustoria or sucking roots which go into the vascular bundles of the host plant and absorb from them the prepared food materials [illegible] total parasites or sapro- [illegible] into the tissue of the host [illegible], and absorb the necessary food materials. Parasitic bacteria infect living plants and animals and absorb food from their bodies.

2. **Saprophytes** (see p. 19). Saprophytic phanerogams such as Indian pipe (*Monotropa*—see FIG. I/26), some orchids, saprophytic fungi and saprophytic bacteria grow on decaying animal or vegetable matter, and absorb the organic food from it.

3. **Symbionts** (see p. 19). Two organisms living in close association with each other being of mutual benefit are called symbionts, and the condition is known as symbiosis. Lichen, mycorrhiza, etc., are illustrative examples.

4. **Carnivorous Plants.** These plants are known to capture lower animals of various kinds, particularly insects. They digest the prey and absorb the nitrogenous products (proteins) from their body. Being green in colour they can manufacture their own carbohydrate food. Altogether over 450 species of carnivorous plants have till now been discovered representing 15 genera belonging to 5 or 6 families; of them over 30 species occur in India.

Classified according to their systematic position

(a) *Droseraceae* (100 sp.), e.g. *Drosera* (90 sp.)—cosmopolitan, *Dionaea* (1 sp.)—the United States, *Drosophyllum* (1 sp.)—Morocco, Spain and Portugal, Aldrovanda (1 sp.)—Europe, Asia and Australia.

(b) *Sarraceniaceae* (12 sp.), e g. *Sarracenia* (7 sp.)—Atlantic North America, *Darlingtonia* (1 sp)—California, and *Heliamphora* (4 sp)—Guiana.

(c) *Nepenthaceae* (60 sp), e g. *Nepenthes* (60 sp.)—Malaysia, Australia, India and Madagascar.

(d) *Cephalotaceae* (1 sp.), e g. *Cephalotus* (1 sp)—Australia.

(e) *Lentibulariaceae* (250 sp.), e.g. *Utricularia* (210 sp.)—cosmopolitan, *Pinguicula* (30 sp)—north temperate regions and temperate Himalayas.

Classified according to their mode of catching the prey

(a) Plants with sensitive glandular hairs secreting a sweet viscid glistening substance, e g. sundew (*Drosera*), butterwort (*Pinguicula*) and *Drosophyllum*

(b) Plants with special sensitive hairs—trigger hairs—on the leaf-surface, e g. Venus' fly-trap (*Dionaea*) and *Aldrovanda. Aldrovanda* is an aquatic plant

(c) Plants with leaves modified into pitchers, e g. pitcher plant (*Nepenthes*)—leaf partly modified into pitcher, other pitcher plants (*Sarracenia, Darlingtonia, Heliamphora and Cephalotus*)—entire leaf modified into pitcher.

(d) Plants with leaf-segments modified into bladders, e.g. bladderwort (*Utricularia*). Bladderworts are mostly aquatic plants.

(1) Sundew (*Drosera*; FIG. 26)—90 sp. Only 3 species, viz. *D. peltata, D. burmanni* and *D. indica*, have been found in India. They are small herbs. Each leaf is covered on the upper surface with numerous glandular hairs known as the tentacles. Each gland, which is reddish in colour, secretes a kind of viscous fluid which glitters in the sun like dew-drops and hence the name 'sundew'. The gland is sensitive and reacts only to chemi- [illegible] that [illegible] substances. No movement [illegible] alights on the leaf, it gets entangled in the sticky fluid, and the tentacles stimulated by the digestible compounds present in the body of the insect bend down on it from all sides and cover it.

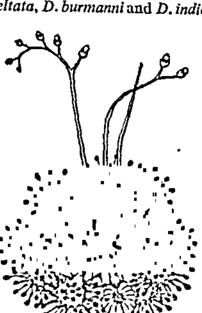


FIG. 26. Sundew (*Drosera*).

When it is suffocated to death the process of digestion begins. The tentacles remain bent over the insect until all the nitrogenous com-

pounds contained in its body have been absorbed. Digestion is extracellular in all carnivorous plants. The glands secrete an enzyme, called *pepsin hydrochloric acid*, which acts on the insect and changes the proteins of its body into soluble and simple forms. The products of digestion are then absorbed by the leaf. The carbonaceous materials are rejected in the form of waste products.

If the tentacles be poked with any hard object, they show no movement nor does any secretion of the enzyme take place. On the other hand, if a bit of raw meat be placed on the leaf, the tentacles bend over it and the glands begin to secrete the enzyme.

(2) **Butterwort** (*Pinguicula*; FIG. 27)—30 sp. Only 1 species has been recorded from India, and that is *Pinguicula alpina*. It grows in mossy beds in the alpine Himalayas at an altitude of 3,000 to 4,000 m. The species of butterwort are small herbs with a scanty development of roots. The surface of the leaf is covered with numerous glands—some sessile and some stalked, the former being water-secreting and the latter mucilage-secreting in nature. When any small insect alights on the leaf, it gets caught by the sticky glands. Stimulated by the presence of proteins in the insect body the margins of the leaf roll inwards enclosing it. The sessile glands then begin to secrete *pepsin hydrochloric acid* which carries on the digestion of proteins. Digested products are then absorbed by the plant. After digestion and assimilation the leaf unrolls again. Carnivory in butterwort was studied by Darwin who found that meat, egg-white, cartilage, small seeds, pollen grains and other substances containing nitrogen, when placed on the leaf, caused secretion of the enzyme, while those containing no nitrogen excited no secretion.

FIG. 27. Butterwort (*Pinguicula*).

(3) Venus' Fly-trap (*Dionaea muscipula*; FIG. 28)—1 sp. The plant is a native of the U.S.A. It is herbaceous in nature and grows in damp mossy places. Each half of the leaf-blade is provided with three long pointed hairs—trigger hairs—placed triangularly on the leaf-surface. The hairs are extremely sensitive from base to apex. The slightest touch to any of these hairs is sufficient to bring about a sudden closure of the leaf-blade, the mid-rib acting as the hinge. The upper surface of the leaf is thickly covered with reddish digestive glands. When the insect is caught, or any nitrogenous material such as meat, fish, etc., placed on the leaf, it closes suddenly and the glands begin to secrete the enzyme *pepsin hydrochloric acid*. The

enzyme then brings about the digestion of proteins contained therein. The acid is stronger in this case than in most other carnivorous plants.

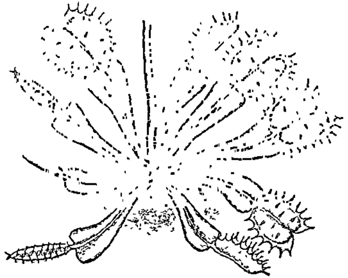


FIG. 28. Venus' fly-trap (*Dionaea*).

(4) Water fly-trap (*Aldrovanda vesiculosa*; FIGS. 29-30)—1 sp. This plant is very widely distributed over the earth. It has been found in abundance in the salt-lakes of the Sundarbans, salt-marshes south of Calcutta, the freshwater 'jheels' of East Pakistan and in several tanks in Manipur. *Aldrovanda* may be regarded as a minia-

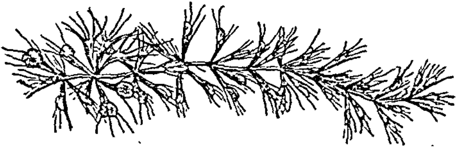


FIG. 29. Water fly-trap (*Aldrovanda*).

ture *Dionaea* in some respects. It is a rootless, free-floating plant with whorls of leaves. The mechanism for catching the prey is practically the same as that of *Dionaea*, but instead of only six sensitive hairs there is a number of them here on either side of the mid-rib, and the leaf is protected by some bristles. There are, of course, numerous digestive glands on the upper surface of the leaf, and the margins beset with minute teeth pointing inwards.

(5) Pitcher Plant (*Nepenthes*; FIGS. 31 & I/66)—60 sp. Only 1 species (*Nepenthes khasiana*) has been found in India (in the Khasi

Jaintia and Garo hills of Assam). Pitcher plants are herbs or climbing undershrubs which often climb by means of tendrils. The pitcher itself is the modification of the leaf-blade, the tendrillar stalk supporting the pitcher is the modification of the petiole, and the laminated structure that of the leaf-base. Each pitcher varies from 10 to 20 cms or even more in height. When it is young the mouth of the pitcher remains closed by a lid which afterwards opens and stands more or less erect. Below the mouth the inside of the pitcher is covered with numerous smooth and sharp hairs, all pointing downwards. Lower down, the inner surface is studded with numerous large digestive glands, each with a hood hanging down over it. Animals, as they enter, slip down the smooth surface, having lost their footing, and get drowned in the fluid that partially fills the cavity of the pitcher. After their death the process of digestion commences. The digestive power of the pitcher of *Nepenthes* was first discovered by Hooker in 1874. The digestive agent, secreted by the glands, is in the nature of a *trypsin*, as was first shown by Vines in 1877. It not only digests the proteins into peptones, but also changes the latter into amines. Amines are readily absorbed by the pitcher. Bits of egg-white, meat, etc., dropped into it, as was first found by Hooker, are seen to be dissolved and ultimately absorbed in the form of amines. Carbohydrates and other materials remain undigested in the pitcher as waste products.

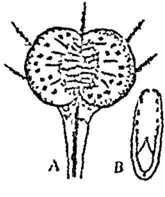


FIG. 30.

FIG. 31.

FIG. 30. *Aldrovanda*; *A*, an entire leaf open; *B*, section of a closed leaf. FIG. 31. A pitcher of pitcher plant. See also FIG. 1/66.

(6) Bladderwort (*Utricularia*; FIG. 32)—210 sp. Over 20 species have been found to occur in India—*U. flexuosa* is a very common one. They are mostly floating or slightly submerged, rootless, aquatic herbs; there are a few terrestrial species also. The leaves are very much segmented, and these simulate roots excepting that they are green in colour. Some of these segments become transformed into *bladders*. Each bladder is about 3-5 mm. in diameter and is provided with a trap-door entrance. The trap-door acts as a sort of valve which can be pushed open inwards from outside, but never from inside to outside. Very small aquatic animals enter by bending the free end of the valve which easily gives way. After their entrance the valve shuts itself automatically, leaving no chance for them to es-

cape. The inner surface of the bladder is dotted all over with numerous digestive glands which vary somewhat in shape. Their function

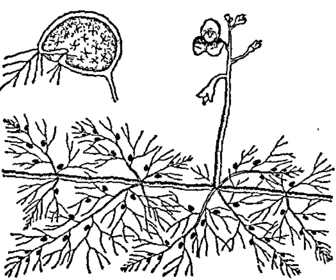


FIG. 32. Bladderwort (*Utricularia*) with many small bladders; *top*, a bladder in section (magnified).

is to secrete the digestive agent and absorb the digested products. A bit of raw meat, pushed inside the bladder, is found to disappear within a few days.

Chapter 8 TRANSLOCATION AND STORAGE OF FOOD

Translocation

teins, sugars, amines and amino-acids travel downward through the sieve-tubes and to some extent through the phloem parenchyma. Such materials can easily pass through the perforated sieve-plates. The protoplasmic threads extending through the pores in the sieve-

plates also help in this respect. The companion cells are used to transmit food substances sideways to the medullary ray cells, the xylem parenchyma and the surrounding cells.

Soluble nitrogenous substances and soluble carbohydrates (sugars) after they are formed in the mesophyll of the leaf move by slow diffusion towards the vascular bundles. They pass through the border parenchyma and enter into the phloem. The phloem extends through the whole length of the plant body so that any soluble compound can be easily transported from the leaves to most of the organs, particularly the storage ones. In the storage organs complex proteins and starch grains are formed, and a gradual accumulation of them takes place in these organs. Later during the period of active growth —formation of buds and flowers—the various forms of stored food are rendered soluble and, therefore, suitable for travelling. Now an upward movement of the soluble food materials takes place through the phloem and finally they are brought to the growing organs. At this time of active growth a part of the food also moves upward through the xylem. The forces responsible for the downward or upward movement of food through the phloem are not known.

That the phloem is definitely the principal channel for conduction of food can be proved by chemical analysis of its contents. Such analysis reveals the presence of soluble carbohydrates (sugars), proteins and other nitrogenous compounds in it. Besides, by 'ringing' or 'girdling' experiments it can be shown that the phloem is the main conduction channel through which the food is primarily moving downwards. Thus if a ring of bark completely encircling a branch be removed down to the wood (evidently including phloem), swellings and later buds appear just above the ring or girdle due to accumulation of food which cannot move further down, the phloem having been removed. If such a girdle be made at the base of a flowering branch, very large flowers and fruits may be produced for the same reason. Similarly, if a ring of bark be removed from the lower end of a cut leafy branch (say, of garden croton) and the cut end dipped into water, roots are seen to develop only above the girdle where food has accumulated, phloem having been removed with the ring. These experiments prove that phloem is responsible for carrying food materials downwards.

Storage

Food is prepared in excess of the immediate need of plants. This surplus food exists in plants in two conditions—either *suitable for travelling* or *suitable for storage*. The travelling form is characterized by *solubility*, and the storage form by *insolubility* in the cell-sap.

Storage Tissues. Tissues meant for storage of food have thin cellu-

lose walls. The cells are mostly parenchymatous in nature. If the walls are thick they are provided with many simple pits in them. Storage cells are also living so that the protoplasm can secrete the necessary enzymes and render the food materials soluble or insoluble, according as translocation or storage is required. All parts made of large-celled parenchyma always contain a certain amount of stored food. Cortex of the root is particularly rich in it, and so also the large pith of the monocotyledonous root. There is also a quantity of food stored up in the endodermis, pith, medullary rays and xylem parenchyma of the stem. Border parenchyma of the leaf also has a store of food in it.

Storage Organs. [illegible]
in the thick cot[illegible]
of the embryo [illegible]
able amount of food stored up. Food is specially stored up in the fleshy roots such as the fusiform, napiform, conical and other roots, and in the underground modified stems such as the rhizome, tuber, corm, etc. All fleshy stems and branches, as in many cacti and spurges (*Euphorbia*), succulent leaves, as in Indian aloe (*Aloe vera*), American aloe (*Agave*), purslane (*Portulaca*), etc., and fleshy scales of onion always contain a store of food in them. The swollen stem-base of kohl-rabi and the gouty stem of *Jatropha podogarica* also contain stored food. Stores of food may also be detected in the growing regions and in the floral organs.

Forms of Stored Food. The various forms in which the food materials are stored in these different organs and tissues may now be considered. The food materials may be carbohydrates, proteins, or fats and oils (see also pp. 147-54).

I. CARBOHYDRATES

Starch (see FIGS. II/13-14). This is of universal occurrence in plants with the exception of fungi. As soon as sugar is formed in the leaf it is converted into starch. This starch is in the form of minute bodies [illegible]
of leucoplasts. The starch grains deposited by the leucoplasts are much bigger in size and have a distinct, stratified appearance. Starch is insoluble in water, and is stored up as such for a longer or shorter period. When growth of the plant is taking place starch is again converted into sugar which then travels from the storage organs to the growing regions, and is eventually made use of by the protoplasm for its nutrition and growth.

Glycogen. In fungi the carbohydrate is stored in the form of glyco-

gen. It is allied to starch and is readily converted into sugar. It is a white amorphous powder, and dissolves in hot water. It is coloured reddish brown by iodine solution.

Inulin (see FIG. II/12). This is a soluble carbohydrate and has the same chemical composition as starch. It is found in the underground parts of some *Compositae*, *Liliaceae* and *Amaryllidaceae*. It may be converted into some form of sugar.

Sugars. Grape-sugar is the first carbohydrate formed in the green leaves of plants. But as soon as it is formed it is usually converted into starch. It is only in a few cases such as grape, onion, etc., that grape-sugar is stored up as such. Cane-sugar occurs as reserve food in sugarcane, banana, pineapple, beet, etc. Grape contains 12-15% of glucose and sugarcane contains 10-15% of sucrose.

Hemicellulose (see FIG. II/6). This occurs as a thickening matter in the cell-wall of the endosperm of the date seed. It may be converted into some form of sugar by the action of the enzyme *cytase*.

II. NITROGENOUS MATERIALS

Proteins. These are the most complex and at the same time the most important substances. Proteins are the chief constituents of protoplasm and nucleus, and consist of carbon, hydrogen, oxygen, nitrogen and sometimes sulphur and phosphorus; but their exact chemical composition is not known. There are various kinds of proteins found in plants as food, and they occur in three distinct conditions, viz. as definite oval or rounded granules known as the aleurone grains; as amorphous proteins (i.e. with no definite shape); and as soluble proteins which occur in solution in the cell-sap. Aleurone grains (see FIG. II/15) occur abundantly in seeds associated with starch, as in pea, bean, etc., or with oil, as in castor. When they occur with oil they are fairly big in size. The other two kinds of proteins occur in bulbs, tubers and in other storage organs.
Amino-acids and Amines. These are much simpler nitrogenous substances than proteins, and occur in solution mostly in the growing regions. Less frequently they occur in the storage tissues.

III. FATS AND OILS

Fats and oils are found in all groups of plants and in almost all living cells of the plant body. In angiosperms they are specially common in seeds and fruits. When oil is in great preponderance usually very little carbohydrate is present. Similarly, when starch occurs in abundance little oil is found. Big aleurone grains often accompany fats and oils, as in castor seed. At ordinary temperature fats are solid and oils are liquid. They are not soluble in water or

in alcohol (except castor oil); all of them are, however, soluble in ether, petroleum, chloroform, etc. They occur in the form of globules in the protoplasm often saturating it. They are formed from fatty acids and glycerine (see p. 153).

It is known that these substances enter into the composition of protoplasm; but they undergo many chemical changes before they are utilized by the protoplasm. They are decomposed by the enzyme [illegible] to the growing regions where they are utilized by the protoplasm. Both of them may readily pass through cell-walls.

Food Stored in the Seed. There is always a considerable amount of food stored up in the cotyledons and in the endosperm of the seed for the use of the embryo as it grows. Food materials occur there in insoluble forms and these are first digested, i.e. rendered soluble and chemically simpler under the action of specific enzymes (see next chapter), and then utilized by the growing parts of the embryo for various purposes such as nutrition and growth of the protoplasm, cell-formation, development of the embryonic parts and also for vigorous respiration. Common forms of such food materials are the following. (1) **Starch**—this is a very common form of carbohydrate stored up in the seed. Cereals such as rice, wheat, maize, oat, barley, etc., are particularly rich in starch. (2) **Hemicellulose**—this is deposited as thickened cell-walls of the endosperm of many palm seeds, e.g. date-palm, betel-nut-palm, nipa-palm, vegetable ivory-palm, etc., and also in some other seeds, e.g. coffee, mangosteen, etc. (3) **Oils**—these are deposited in most seeds to a greater or less extent. There is a special deposit of them in seeds like groundnut, gingelly, coconut, castor, safflower, etc. (4) **Proteins**—these also occur in all seeds in varying quantities. In seeds like pulses they occur in fairly high percentage. Soybean contains 42-47% of proteins. Oily seeds also contain a high percentage of proteins, e.g. castor seed.

Chapter 9 DIGESTION AND ASSIMILATION OF FOOD

Digestion

The reserve materials are generally insoluble in water or cell-sap and also indiffusible but when translocation is necessary they are rendered soluble and diffusible by the action of enzymes. It is only in the soluble forms that food materials are absorbed by the protoplasm. *This rendering of insoluble and complex food substances into soluble and simpler forms suitable for translocation through the plant body and assimilation by the protoplasm is collectively known as* **digestion.**

The process of digestion is chiefly intra-cellular, that is, it takes place inside the cell. Extra-cellular digestion occurs in a few cases, as in carnivorous plants, parasites, fungi and bacteria. In such cases the digestive agent or enzyme is secreted by the protoplasm outside the cells, where it digests or splits up the complex food materials; the products of digestion are then absorbed by the cells. Digestion, like all other physiological functions, is performed by the protoplasm. For this purpose it secretes different kinds of digestive agents or enzymes to act on different kinds of food substances. Enzymes concerned in intra-cellular digestion are called *endoenzymes*, and those concerned in extra-cellular digestion *exoenzymes*.

Enzymes. Enzymes are organic catalysts secreted by the protoplasm to act upon and digest insoluble and complex foodstuff and render it soluble and easily assimilable without themselves undergoing any chemical change. They also bring about a number of chemical reactions in many other substances occurring or formed in the plant body or the animal body. They also act upon soluble materials and split them up into simpler compounds. They bring about hundreds of such chemical changes in the living cells of the plant or the animal. All living cells secrete one or more enzymes, often at one time, according to their need. The term 'enzyme' was first applied by Kühne in 1876 to the plant juice which, as he found, could bring about digestion of certain chemical compounds. In 1897 Buchner first discovered that extract from crushed yeast cells could bring

to them. The enzyme 'urease' was first isolated by Sumner in 1926 in crystalline form. Since then several enzymes have been obtained in pure crystalline form. Enzymes are very complex chemical substances made of large and heavy molecules. They occur in the form

[illegible] in the protoplasm which may secrete one or more enzymes [illegible] They are soluble in water, alcohol, dilute glycerine, and in [illegible] acid or alkali. Some enzymes consist entirely of proteins, e.g. [illegible] proteolytic enzymes and amylases which act directly on the [illegible] There are, however ...

[illegible] part is firmly att... group or a coenzyme). When the ... and is not ... etic group, ... by dialy- ... the oxidizing-reducing enzymes ... without the presence group. The latter may be a metal or an organic compound with a metal. Thus the enzymes tyrosinase and ascorbic acid oxidase have a protein portion and a copper atom. Cytochrome oxidase, catalase and peroxidase contain iron (as iron porphyrin). Likewise zinc, manganese, cobalt, nickel, magnesium, etc., may form prosthetic groups of certain enzymes. In such cases the prosthetic groups act as specific *activators*. Some oxidizing enzymes (respiratory and fermenting) contain organic compounds as prosthetic groups. The coenzyme components of many enzymes include a variety of compounds. The protein portion and the coenzyme may occur separately in the same cell but they must be linked together or closely associated for the whole enzyme to be effective. The same prosthetic group or coenzyme may combine with different kinds of proteins and form different kinds of enzymes. Several vitamins (e.g. vitamin B complex) are now considered as forming coenzyme components of many enzymes. Similarly DPN and TPN of the dehydrogenase group act as coenzymes. Zymogen. Cells sometimes do not directly produce an enzyme but at first a chemical precursor of an enzyme, known as zymogen, is secreted by the protoplasm. The zymogen then becomes converted into an active enzyme. Many ki... o- ...ns have been identified so far ... d they are now ... m- ...ne with different protein ... nts as prosth... or enzymes to form differen... enzymes.

agent; this means that the presence of the enzyme induces some chemical reaction in a particular substance without itself undergoing any chemical change. Thus the enzyme may be regarded as an organic catalyst. After its action is over it breaks down and disappears. (3) *Inexhaustibility.* The enzyme is never exhausted while it works, i.e. a small quantity of it can act on an almost unlimited supply of the substance provided that the products of its action are removed from the seat of its activity. (4) *Colloidal Nature.* Enzymes occur in the protoplasm in the form of colloids Enzyme molecules are very large and fall within the colloidal system. They have high molecular weights, and being very large in size diffuse slowly and can in many cases be more or less easily separated by dialysis. (5) *Reversible Action.* Some enzymes can bring about reactions in both directions. For example, the enzyme lipase can bring about synthesis of fats from glycerine and fatty acid, and can under certain other conditions decompose fats into glycerine and fatty acid. This is also true of some proteolytic enzymes, dehydrogenases and transferring enzymes. (6) *Sensitivity to Heat.* Most enzymes in liquid medium are destroyed at a temperature of 70° C. In dry seeds and spores the enzymes can often stand a temperature of 100-120° C., at least for some time. The enzymes extracted from plant tissues can also stand this high temperature. (7) *Activators and Inhibitors.* There are certain compounds (particularly the prosthetic group) which accelerate the activity of certain enzymes. There are others which inhibit their action or even destroy them.

Classification of Enzymes. Enzymes have been classified in different ways by different authors. A general classification is based on the kinds of reactions that they catalyse, as follows. In addition to those given below several other enzymes occur or may be formed in the living plant cells.

1. HYDROLYSING (OR HYDROLYTIC) ENZYMES OR HYDROLASES

A. Carbohydrases. (1) *Diastase* (or amylase) hydrolyses starch to dextrin and maltose. (2) *Maltase* hydrolyses maltose to glucose. (3) *Invertase* (or sucrase) hydrolyses sucrose to fructose and glucose. (4) *Inulase* hydrolyses inulin to fructose. (5) *Cellulase* hydrolyses cellulose to glucose. (6) *Cytase* hydrolyses hemicellulose to glucose. (7) *Emulsin* hydrolyses glucosides to glucose and a non-sugar.

tidases: (4) *Erepsin* hydrolyses polypeptides to amino-acids. (*c*) *Amidases*: (5) *Asparaginase* hydrolyses asparagine to aspartic acid and ammonia.

II. OXIDIZING-REDUCING ENZYMES

D. **Oxidases** are a group of respiratory enzymes which bring about oxidation of certain chemical compounds in the presence of oxygen. *Cytochrome*, a pigmented member of this group closely related to chlorophyll, acts as a hydrogen-carrier. During certain oxidation-reduction processes certain compounds become oxidized with the transfer of hydrogen to cytochrome (hydrogenated or reduced) Under the influence of *cytochrome oxidase* the reduced cytochrome is again oxidized (dehydrogenated) and it goes back to its original condition. Other common oxidases are *tyrosinase* and *ascorbic acid oxidase*.

E. **Catalases** decompose hydrogen peroxide, H_2O_2, to water and molecular oxygen They are very widely distributed in plants.

F. **Peroxidases** decompose H_2O_2 to water and active oxygen causing oxidation of many compounds. They are very widely distributed in plants.

G. **Dehydrogenases** act on many organic compounds, particularly organic acids; for example, they convert ethyl alcohol to acetaldehyde; malic acid to oxalacetic acid; lactic acid to pyruvic acid, etc. These enzymes are probably present in all plants and they act by transferring hydrogen from one compound to another, mostly under anaerobic condition. The compound that releases hydrogen (i.e. dehydrogenated or oxidized) is said to be a *hydrogen-donor*, and the one that receives hydrogen (i.e. hydrogenated or reduced) is said to be a

[illegible]

carbon dioxide.

I. **Zymase**, an enzyme complex, consists of a complex mixture of several enzymes, coenzymes and also inorganic ions, and is concerned in oxidation-reduction processes; a familiar example is the conversion of glucose to ethyl alcohol and carbon dioxide. Harden (1923, 1932) discovered over a dozen enzymes and a number of coenzymes in the zymase complex. Zymase works in the presence of inorganic phosphate.

III. TRANSFERRING ENZYMES OR TRANSFERASES

J. **Phosphorylases** (in the presence of inorganic phosphate—H_3PO_4) catalyse starch or glycogen to glucose phosphate; and sucrose to fructose phosphate+

[illegible]

glucose or fructose+phosphate to glucose- or fructose-phosphate; glucose-phosphate to fructose-phosphate; phosphoglyceric acid to phosphopyruvic acid, etc.

Assimilation

Assimilation *is the absorption of the simplest products of digestion of foodstuff by the protoplasm into its own body and conversion of these products into the similar complex constituents of the protoplasm (the term 'assimilate' means to make similar)*. As a result of assimilation the protoplasm increases in bulk, and the cell-walls are built up. Assimilation is a constructive process by which the

protoplasm is continually reconstructing itself out of the nutritive substances such as sugar and simple products of proteins supplied to it. The various kinds of carbohydrates are converted into sugar, particularly glucose, and the various complex proteins are converted on rapid hydrolysis into peptones, polypeptides and amino-acids. These simplest products of digestion travel to the growing regions where the protoplasm is very active. Glucose is mostly broken down by the living cells during their respiration, releasing energy; a part of glucose supplies new material, particularly cellulose, for growth of cells; and another part of it is precipitated as starch for future use. The digested products of proteins, viz. peptones, etc., are directly assimilated by the protoplasm into its own body, and new complex protoplasmic proteins and nucleoproteins are built out of them. We know that the protoplasm itself is a living substance composed of very complex proteins. The food is, therefore, changed into complex protoplasmic proteins. The protoplasm being living, it is natural to suppose that food is changed into 'live' proteins, or, in other words, food passes from non-life into life, that is, protoplasm. This is the goal of nourishment. How this change takes place we do not know. We know only that the protoplasm has the power of bringing it about.

Chapter 10 RESPIRATION AND FERMENTATION

Respiration

Respiration *is essentially a process of oxidation and decomposition of organic compounds, particularly simple carbohydrates such as glucose, in the living cells with the release of energy.* The most important feature of respiration is that by this oxidative process the *potential* energy stored in the organic compounds in living cells is released in a stepwise manner in the form of active or *kinetic* energy under the influence of a series of enzymes and is made available, partly at least, to the protoplasm for its manifold vital activities such as manufacture of food, growth, movements, reproduction, etc. Often a considerable amount of energy escapes from the plant body in the form of heat, as seen in germinating seeds. The reserve food materials that undergo oxidation are mostly simple carbohydrates, principally glucose, and sometimes also, particularly in the absence of glucose, other substances such as complex carbohydrates, proteins

and fats; these are of course first hydrolysed and then oxidized. The main facts associated with respiration are: (1) consumption of atmospheric oxygen, (2) oxidation and decomposition of a portion of the stored food resulting in a loss of dry weight as seen in the seeds germinating in the dark, (3) liberation of carbon dioxide and a small quantity of water (the volume of CO_2 liberated being equal to the volume of O_2 consumed) and above all, (4) release of energy by the breakdown of organic food. The over-all chemical reaction may be stated thus: $C_6H_{12}O_6+6O_2=6CO_2+6H_2O$+Energy (sugar +oxygen=carbon dioxide+water+energy). This shows that for oxidation of one molecule of sugar six molecules of oxygen are used and that six molecules each of CO_2 and H_2O are formed. By burning sugar at a high temperature CO_2 and H_2O are also formed but in the living cells this process is carried on by a series of enzymes at a comparatively low temperature. Oxidation may be complete, as shown in the above formula, with the formation of carbon dioxide and water as end products, the former escaping from the plant body and the latter getting mixed up with the general mass of water in the cells; or, it may be incomplete with the formation of organic acid or ethyl alcohol and carbon dioxide, as represented by the equation: $C_6H_{12}O_6=2C_2H_5OH+2CO_2$ (sugar=ethyl alcohol+carbon dioxide). The mere exchange of gases—oxygen and carbon dioxide—is, however, known as *breathing* and is a characteristic feature of animals. The oxygen gas, after entering through the stomata, diffuses through the intercellular spaces into the cells and slowly oxidizes not only glucose and other carbohydrates but also, though less frequently, other organic materials—like fats, proteins, organic acids and even protoplasm under extreme conditions. The carbon dioxide that is formed in respiration diffuses through the intercellular spaces and finally escapes through the stomata and the lenticels into the surrounding air; a portion of it may be retained in the cells and used for photosynthesis. In submerged aquatic plants the surrounding water containing dissolved air supplies the necessary gases for respiration and carbon-assimilation.

while adult organs do so comparatively slowly. The gases normally enter the plant through the stomata. But these are closed at night. So, to facilitate the interchange of gases concerned, special structures are developed on the branches. These are the lenticels. Unlike the stomata they remain open. For easy diffusion of gases in the interior of the plant body, there is developed a network of air-cavities and intercellular spaces which are connected throughout

and are continuous with the stomata and the lenticels (see experiment 28).

In respiration the cells are continually exhaling carbon dioxide, and in photosynthesis the green cells are continually making use of this gas during the daytime and giving off oxygen. But the latter process goes on more vigorously than the former, and practically masks it. Thus in green parts of plants the composition of the intercellular air varies, becoming much richer in oxygen during the daytime, but richer in carbon dioxide during the night. The amount of nitrogen varies very little, as this gas is not made use of by the protoplasm. Since in respiration plants are continually exhaling carbon dioxide, the atmosphere has a tendency to become richer in this gas, especially at night. Carbon dioxide is a suffocating gas, and is likely to vitiate the atmosphere. But then during the day the green plants absorb it for photosynthesis and give out oxygen which goes back to the atmosphere. The atmosphere is thus purified, and the composition of the air remains constant.

Experiment 28. Aeriferous system of the plant (FIG. 33). Take a wide-mouthed bottle and a cork of appropriate size with two holes bored in it. Partially fill the bottle with water and insert the long petiole of a selected broad leaf (e.g. *Begonia*) into the water through a hole in the cork. Through the other hole introduce a bent tube with its inner end clear above the surface of water. All the connexions are made air-tight by applying paraffin-wax, and the air drawn out from the bottle through the bent tube, preferably with a vacuum pump. As this is done a series of minute bubbles is seen to escape through the cut end of the petiole and rise upwards. Repeat the experiment after applying a coat of vaseline on the surfaces of the leaf and see that no air-bubbles appear. This escape of air-bubbles indicates that there is an intercommunicating system of intercellular spaces connected with the stomata, forming as a whole the aeriferous system of the plant.

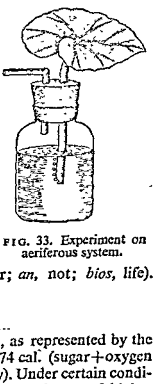


FIG. 33. Experiment on aeriferous system.

Aerobic and Anaerobic Respiration (*aer*, air; *an*, not; *bios*, life).

amount of energy is released by this process, as represented by the equation—$C_6H_{12}O_6+6O_2=6CO_2+6H_2O+674$ cal. (sugar+oxygen =carbon dioxide+water+674 cal. of energy). Under certain conditions, as in the absence of free oxygen, many tissues of higher plants, seeds in storage, fleshy fruits and succulent plants like cacti temporarily take to a kind of respiration, called anaerobic respiration, which results in incomplete oxidation of stored food and

formation of carbon dioxide and ethyl alcohol, and sometimes also various organic acids such as malic, citric, oxalic, tartaric, etc. Very little energy is released by this process to maintain the activity of the protoplasm. This may be represented by the equation—$C_6H_{12}O_6 = 2C_2H_5OH + 2CO_2 + 28$ cal. (sugar=ethyl alcohol+carbon dioxide +28 cal. of energy). It is otherwise known as *intramolecular respiration* because in this process intramolecular oxidation of sugar and other compounds takes place without the use of free oxygen. Anaerobic respiration may continue only for a limited period of time, at most a few days, after which death ensues, evidently due to low production of energy and accumulation of toxic substances in the cells. In certain micro-organisms (certain bacteria, yeast and some other fungi), however, the fundamental process of energy-release is anaerobic respiration. Anaerobic respiration resulting in the production of alcohol is otherwise called alcoholic fermentation.

Mechanism of Respiration. Chemical changes in respiration are more or less definitely known. It is known that the whole process of respiration is controlled by a group of enzymes, called *respiratory enzymes*, working step by step, and that it is complete in two stages: an anaerobic phase and an aerobic phase. The first or anaerobic [illegible]

and water is called **Krebs cycle**. Several reactions, possibly over 20, take place in the whole process, each reaction being controlled by a specific enzyme. At the initial or anaerobic phase of respiration a simple carbohydrate like glucose or fructose is first phosphorylated (phosphate group added); this is a very important initial step leading to the formation of phosphoglyceric acid and finally pyruvic acid. By the reactions in this anaerobic phase very little energy is made available to the cells. All the reactions in this phase are reversible. The principal enzymes concerned in the breakdown of glucose to pyruvic acid (glycolysis) and the reactions involved in a stepwise manner are: *phosphorylases* in the presence of H_3PO_4 (starch or glycogen ⇄ glucose-1-phosphate; sucrose ⇄ fructose+glucose-1-phosphate); *hexokinase* (a transphosphorylase) in the presence of ATP[2] which is a phosphate-donor (glucose ⇄ glucose-6-phosphate); glucose-1-phosphate and glucose-6-phosphate are readily interconvertible in the plant cells under the action of a speci-

volved in respiration are of the second (*b*) type.

[2] ATP=adenosine triphosphate.

fic enzyme; some specific *transphosphorylases* in the presence of ATP (glucose-6-phosphate $\rightleftharpoons$ fructose-6-phosphate $\rightleftharpoons$ fructose-6-diphosphate); *adolase*, a very stable enzyme (fructose diphosphate $\rightleftharpoons$ glyceraldehyde-3-phosphate); certain other *transphosphorylases* in the presence of ADP[1] (glyceraldehyde-3-phosphate $\rightleftharpoons$ 3-phosphoglyceric acid $\rightleftharpoons$ 2-phosphoglyceric acid); *endolase* in the presence of magnesium (2-phosphoglyceric acid $\rightleftharpoons$ 2-phosphopyruvic acid); *phosphopyruvate* (a transphosphorylase) in the presence of ADP (2-phosphopyruvic acid by losing its phosphate $\rightleftharpoons$ pyruvic acid). The formation of pyruvic acid is the end of glycolysis or the initial or anaerobic phase of respiration. It may be noted that one molecule of sugar yields two molecules of pyruvic acid.

Pyruvic acid holds a key position at this stage from which under different conditions reactions may proceed in different directions. Thus in the second phase if phosphoglyceric acid and hydrogen-donor be available the pyruvic acid will work in the reverse direction finally producing sugar. In normal respiration, however, with the access of oxygen (**aerobic phase**) the pyruvic acid is completely oxidized by a group of enzymes, called *oxidases* (catalase, peroxi- [illegible]

extracted from plants and these have been found to bring about reactions *in vitro* similar to those *in vivo*. Some of the vitamins (vitamin B complex) and respiratory pigments (flavoproteins and cytochromes) also take part in some of the intermediate reactions. As stated before, the end-products in the aerobic phase of respiration are carbon dioxide and water. (For further details see the note on Krebs cycle below.) In the absence of oxygen the anaerobic phase may continue for some time in higher plants, while it is the usual mode of respiration in many of the lower plants (many bacteria and fungi). In any case the pyruvic acid is incompletely oxidized into ethyl alcohol and carbon dioxide, and in many of the higher plants into various organic acids. At first under the action of the enzyme *carboxylase* in the presence of the coenzyme *cocarboxylase* the pyruvic acid is converted into acetaldehyde and carbon dioxide; acetaldehyde takes up hydrogen under the action of a *dehydrogenase* in the presence of $DPNH_2$ and is reduced to ethyl alcohol. Very little energy is made available to the plant cells by this process.

Krebs Cycle. It is now known that several simple organic acids in plants such [illegible] CO_2, the former immediately combines with oxaloacetic

[1] ADP = adenosine diphosphate.

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Krebs Cycle. It is now known that several simple organic acids in plants such as citric, succinic, fumaric, malic, etc., which are important constituents of plant tissues, form intermediate products in the complete oxidation of pyruvic acid to carbon dioxide and water. Pyruvic acid breaks up into a 2-carbon fragment and a molecule of CO_2; the former immediately combines with oxalacetic

[1] ADP = adenosine diphosphate

acid and becomes converted into citric acid. The citric acid in turn passes through a series of organic acids in a stepwise manner until malic acid is formed, from which finally oxalacetic acid is reconstituted. The cyclic pathway thus followed by pyruvic acid through various organic acids with the evolution of CO_2 and

cycle which is thus kept going without interruption.

Experiment 29. Aerobic respiration (FIG. 34). Respiration in plants can be experimentally proved in a very simple but efficient way by the following method.

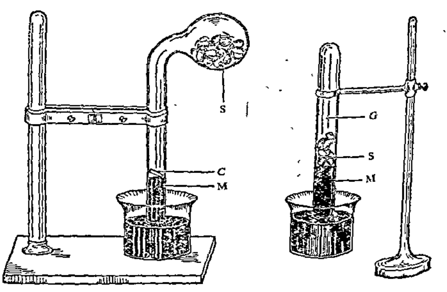


FIG. 34. FIG. 35.

Experiments on Respiration. FIG. 34. Aerobic respiration. FIG. 35. Anaerobic or intramolecular respiration. *S*, seeds; *C*, caustic potash stick; *M*, mercury; *G*, gas.

into the beaker and invert the respiroscope over it. The respiroscope is fixed

acid and becomes converted into citric acid. The citric acid in turn passes through a series of organic acids in a stepwise manner until malic acid is formed, from which finally oxalacetic acid is reconstituted. The cyclic pathway thus followed by pyruvic acid through various organic acids with the evolution of CO_2 and water, as first formulated by Krebs, an English biochemist, in 1943, is known as Krebs cycle. For each molecule of pyruvic acid three molecules of CO_2 are evolved and five atoms of oxygen are consumed. It may be noted that the reactions are controlled by certain specific enzymes. It may further be noted that the 2-carbon fragment of the oxidized pyruvic acid is continuously fed into this cycle which is thus kept going without interruption.

Experiment 29. Aerobic respiration (FIG. 34). Respiration in plants can be experimentally proved in a very simple but efficient way by the following method. Appliances required for this experiment are: a flask with a bent bulb, called **respiroscope** (an ordinary long-necked flask will also do), a beaker, a suitable stand with a clamp, a quantity of mercury (according to the size of the beaker), caustic potash stick and some germinating seeds or opening flower-buds. Introduce some germinating seeds into the respiroscope. Pour a quantity of mercury

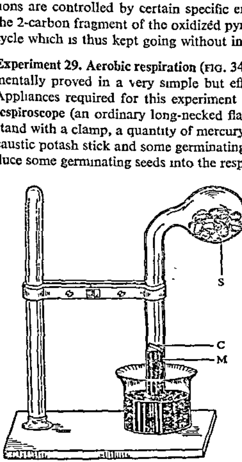


FIG. 34.

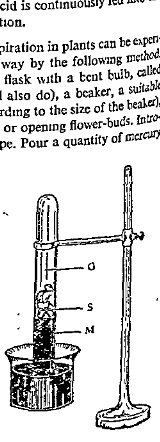


FIG. 35.

Experiments on Respiration. FIG. 34. Aerobic respiration. FIG. 35. Anaerobic or intramolecular respiration. *S*, seeds; *C*, caustic potash stick; *M*, mercury; *G*, gas.

tent of nearly one-fifth of its total volume. *Inference*. Since caustic potash absorbs carbon dioxide we may conclude that the gas absorbed is carbon dioxide

which must have been exhaled by the seeds. It is thus proved that plants give out carbon dioxide in respiration.

Note. The experiment may be carried out in a still simpler way. Instead of mercury, caustic soda or caustic potash solution may be poured into the beaker, and the flask or respiroscope with the germinating seeds inverted over it. Subsequently the caustic solution is noticed rising in the flask or the respiroscope.

Experiment 30. Anaerobic respiration (FIG. 35). Completely fill a short narrow test-tube with mercury (*M*), close it with the thumb and invert it over mercury contained in a beaker. Keep the tube in a vertical position with a suitable stand Take some germinating seeds, and remove the seed-coats from them to get rid of the enclosed air (oxygen). With the help of the forceps hold the skinned seeds under the test-tube, and release them one after another. As soon as released the seeds rise to the closed end of the tube. Introduce in this way five or six seeds. They are now free from oxygen. Prior to their introduction it is better to soak the seeds in distilled water, or to introduce into the test-tube a small quantity of distilled water with the help of a bent tube. This keeps the seeds moist. Note on the following day that the mercury column has been pushed down, owing to the exhalation of a gas (*G*) by the seeds. Within one or two days nearly the whole of the emrcury is seen to be pushed out of the tube. Introduce a small piece of caustic potash stick into the test-tube with the help of the forceps. It floats on mercury, and coming in contact with the gas, absorbs it quickly. The mercury rises again and fills up the test-tube. The gas evidently is carbon dioxide.

Experiment 31. To prove that carbon dioxide is released in respiration of a green plant. Set up the apparatus, as shown in FIG. 36. *A* contains soda-lime; *B* contains KOH solution; *C* encloses a pot plant—the bell-jar stands on a smooth flat plate stuck with vaseline to prevent leakage of air; *D* contains baryta (or

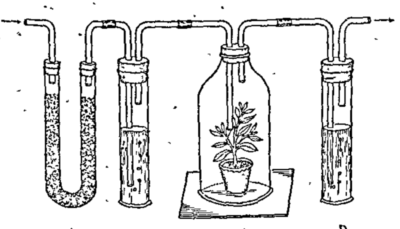


FIG. 36. Experiment on respiration of a green plant.

figure). The stopcock of the aspirator bottle is slightly opened. As a result a partial vacuum is produced and a slow current of air, freed of CO_2, is drawn

in through the other end of the series. After some time, as the air-current slowly passes into *D*, it will be seen that the baryta water in it turns milky (barium carbonate is formed). Evidently *this* CO_2 has been released by the plant.

Note that carbon dioxide is absorbed by caustic potash, baryta water and lime water, but only the latter two turn milky in contact with carbon dioxide

Experiment 32. The volume of CO_2 evolved in respiration is approximately equal to the volume of O_2 absorbed. (*a*) Set up the apparatus, as shown in FIG. 37. The small test-tube in *A* contains KOH solution; *B* is without it. The beaker at the bottom contains water in each case Both the respiroscope-tubes contain some germinating seeds. The stopcock is closed. After some time it is seen that the water rises in *A*, the CO_2 released by the seeds being absorbed by KOH. In *B* there is no rise of water as no vacuum has been produced in it. *B*, therefore, shows that the total volume of air in it (whatever be the gaseous exchanges) is constant. As we know, in respiration O_2 and CO_2 only are involved, it may be taken for granted that the volumes of the two gases are equal. Then replace *B* by a new respiroscope-tube (or use the same one after washing) without seeds and dip it into pyrogallate of potash (instead of water). Soon the solution, as it absorbs O_2, rises to the same extent as in *A*. We may, therefore, conclude that in respiration the volume of CO_2 given out is equal to the volume of O_2 absorbed.

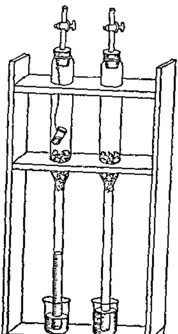

A *B*

FIG. 37. Respiratory quotient–CO_2: O_2 (see experiment 32*a*).

Note that if starchy seeds like pea, gram, etc., are used the respiratory quotient is unity; if, however, oily seeds like castor be used the R. Q. is less than unity, i.e. they absorb more O_2 and give out less CO_2.

opening the hole at the neck of the bulb. By adjusting the height of the side-tube the KOH solution may be brought to the 100 cc. mark in the graduated manometer tube. Now close the hole by turning the stopper. The volume of the enclosed air is 100 cc. and it is at atmospheric pressure. *With the progress of the* experiment more solution is poured into the side-tube to maintain equal levels in the two tubes. As respiration takes place, CO_2 liberated by the seeds is absorbed by the KOH solution, and it rises and stands at the 80 cc. mark. Evidently 1/5th of the air (which is oxygen) has been absorbed by the seeds during

the two tubes, evidently indicating that the volume of oxygen absorbed is the same as that of carbon dioxide exhaled.

Respiration is a destructive process consisting in the decomposition of some of the food materials, more particularly glucose, brought about by the action of specific enzymes secreted by the protoplasm; nevertheless, it is highly beneficial to the life of the plant for the reason that respiration sets free *energy* by which work is performed. This energy is absolutely necessary for the various synthetic processes, growth, movements, etc. If we think of the enormous development of a large tree we can at once realize what a vast amount of energy has been utilized in constructing that body. A considerable amount of energy, of course, escapes from the plant body in the form of heat. During vigorous respiration heat is generated. A thermometer thrust into a mass of germinating seeds will show a marked rise of temperature (see experiment 33). This production of heat is an easily observed form of energy. Respiration results in a loss of dry weight of the plant. This is believed to be due to escape of carbon dioxide.

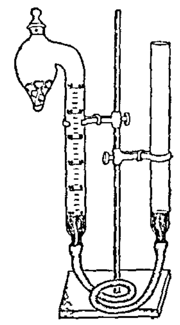


FIG. 38. Ganong's respirometer (see experiment 32*b*).

Experiment 33. Heat generated in respiration (FIG. 39). Take two thermoflasks and fill one (*A*) of them with germinating seeds and the other (*B*) with the same killed by boiling for a few minutes and then soaked in 5% formalin to prevent any fermentation in the flask generating heat. Insert a sensitive thermometer in each as shown in the figure and pack the mouth of the flask with cotton. It is better to place, half immersed in seeds, a small test-tube containing a small piece of caustic potash stick. Wait for some time and note a remarkable rise of temperature in the case of flask *A* containing germinating seeds; while the flask *B* containing killed seeds shows no rise of temperature. This evidently proves that heat is evolved in respiration.

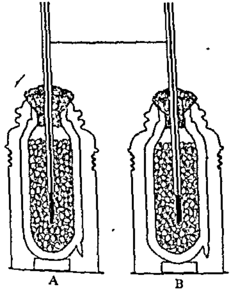


FIG. 39. Experiment to show that heat is generated in respiration.

in through the other end of the series. After some time, as the air-current slowly passes into *D*, it will be seen that the baryta water in it turns milky (barium carbonate is formed). Evidently this CO_2 has been released by the plant.

Note that carbon dioxide is absorbed by caustic potash, baryta water and lime water, but only the latter two turn milky in contact with carbon dioxide.

Experiment 32. The volume of CO_2 evolved in respiration is approximately equal to the volume of O_2 absorbed. (*a*) Set up the apparatus, as shown in FIG. 37. The small test-tube in *A* contains KOH solution; *B* is without it. The beaker at the bottom contains water in each case. Both the respiroscope-tubes contain some germinating

KOH. In *B* there is no rise of water as no vacuum has been produced in it. *B*, therefore, shows that the total volume of air in it (whatever be the gaseous exchanges) is

scope-tube (or use the same one after washing) without seeds and dip it into pyrogallate of potash (instead of water). Soon the solution, as it absorbs O_2, rises to the same extent as in *A*. We may, therefore, conclude that in respiration the volume of CO_2 given out is equal to the volume of O_2 absorbed.

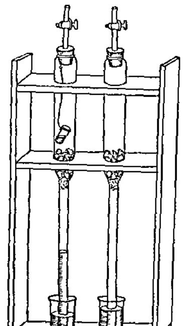


FIG 37 Respiratory quotient C

Note that if starchy seeds like pea, gram, etc, are used the respiratory quotient is unity; if, however, oily seeds like castor be

2 c

pour 10% KOH solution into the side- (or levelling- or reservoir-) tube after opening the hole at the neck of the bulb. By adjusting the height of the side-tube the KOH solution may be brought to the 100 cc. mark in the graduated manometer tube. Now close the hole by turning the stopper. The volume of the en-

sorbed by the KOH solution, and it rises and stands at the 80 cc. mark. Evidently 1/5th of the air (which is oxygen) has been absorbed by the seeds during respiration, and this is the volume of CO_2 exhaled by the seeds during the process, as indicated by the rise of KOH solution. If, instead of KOH solution, saturated common salt solution be used its level is seen to remain constant in the two tubes, evidently indicating that the volume of oxygen absorbed is the same as that of carbon dioxide exhaled.

Respiration is a destructive process consisting in the decomposition of some of the food materials, more particularly glucose, brought about by the action of specific enzymes secreted by the protoplasm; nevertheless, it is highly beneficial to the life of the plant for the reason that respiration sets free *energy* by which work is performed. This energy is absolutely necessary for the various synthetic processes, growth, movements, etc. If we think of the enormous development of a large tree we can at once realize what a vast amount of energy has been utilized in constructing that body. A considerable amount of energy, of course, escapes from the plant body in the form of heat. During vigorous respiration heat is generated. A thermometer thrust into a mass of germinating seeds will show a marked rise of temperature (see experiment 33). This production of heat is an easily observed form of energy. Respiration results in a loss of dry weight of the plant. This is believed to be due to escape of carbon dioxide.

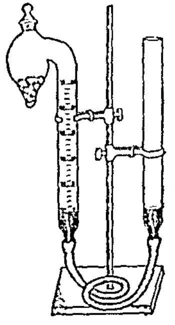


FIG. 38. Ganong's respirometer (see experiment 32*b*).

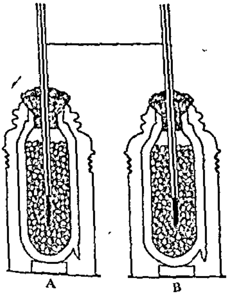


FIG. 39. Experiment to show that heat is generated in respiration.

Experiment 33. Heat generated in respiration (FIG. 39). Take two thermoflasks and fill one (*A*) of them with germinating seeds and the other (*B*) with the same killed by boiling for a few minutes and then soaked in 5% formalin to prevent any fermentation in the flask generating heat. Insert a sensitive thermometer in each as shown in the figure and pack the mouth of the flask with cotton. It is better to place, half immersed in seeds, a small test-tube containing a small piece of caustic potash stick. Wait for some time and note a remarkable rise of temperature in the case of flask *A* containing germinating seeds; while the flask *B* containing killed seeds shows no rise of temperature. This evidently proves that heat is evolved in respiration.

CONDITIONS AFFECTING RESPIRATION

1. **Oxygen.** Presence of oxygen is the first and the most essential condition for respiration since this is an *oxidation* process. The intensity of the process is markedly affected by alteration in the concentration of oxygen in the surrounding air. If the concentration goes below 5% the process rapidly falls off. With gradual increase, however, in oxygen concentration up to even 100% there is a corresponding steady rapidity in the process.

2. **Temperature.** This affects markedly the rate of respiration. The minimum rate is reached at 0°C. or even at 10°C. With the rise of temperature the rate increases and the maximum is reached at 45°C. or even at 40°C. Beyond this point protoplasm is injured and respiration decreases in rate. The optimum temperature, however, lies between 30°C. and 35°C.

3. **Light.** The effect of light is only indirect; in bright sunlight the respiratory activity is greater than in subdued light. This may be due to the fact that in bright light stomata remain wide open and oxygen is easily and quickly absorbed.

4. **Supply of Water.** Protoplasm saturated with water respires more vigorously than that in a desiccated condition, as in the dry seed. Thus with the supply of water the rate of respiration increases.

5. **Vitality of Cells.** Respiration in young active cells is more rapid than in old cells. Vegetative buds, floral buds and germinating seeds respire more vigorously than older parts of the plant body.

6. [illegible]
bo[illegible]
slo[illegible]
moved, respiration again goes on normally.

7. **Nutritive Materials.** Food materials, more particularly soluble carbohydrates, affect respiration to a considerable extent. With the supply of oxygen these materials become quickly broken down.

Respiratory Quotient (R Q). There is a relation between the volume of carbon dioxide evolved and the volume of oxygen consumed in the process of respiration, and the ratio of these two volumes is known as respiratory quotient. Thus when sugars are consumed in respiration, as mostly in cereals, the respiratory quotient (R.Q.), i e. the ratio of CO_2 : O_2 is equal to unity. This means that for one molecule of CO_2 given out one molecule of O_2 is used. Sugars are by no means the only compounds consumed in respiration. Fats, proteins, organic acids and other materials are also consumed, and the R.Q in such cases may vary greatly from unity. When fats are consumed in respiration, as in the oily seeds, the R.Q , i e. the ratio of CO_2 : O_2 is less than unity. Fats are poorer in oxygen than are sugars and, therefore, correspondingly more oxygen is required

for combustion of fats, or, in other words, less CO_2 is evolved for a particular volume of O_2 taken up. Likewise, when proteins are used in respiration, the R.Q. is less than unity since the proportion of oxygen to carbon in them is less than in carbohydrates. When organic acids are oxidized the R.Q. is found to be more than unity; such compounds are relatively rich in oxygen in comparison with carbohydrates. At night succulent plants such as cacti absorb oxygen without giving out carbon dioxide; in them instead of carbon dioxide organic acids (malic, citric, oxalic, etc.) are formed as a result of incomplete oxidation of sugar. During the daytime, however, they give out CO_2. The concept of respiratory quotient is important because it serves as a clue to the nature of compounds used in respiration, and also to the nature of the process itself.

RESPIRATION AND PHOTOSYNTHESIS

1. In respiration plants utilize oxygen and give out carbon dioxide, while in photosynthesis plants utilize carbon dioxide and give out oxygen; that is, one process is just the reverse of the other

2. Respiration is a destructive (catabolic) process, but photosynthesis is a constructive (anabolic) process. In the former process sugar is broken down into CO_2 and H_2O with the liberation of energy, while in the latter process CO_2 and H_2O are utilized to build up sugar with the storage of energy. Respiration is thus a *breaking-down* process, and photosynthesis a *building-up* process.

3. The intermediate chemical reactions in the breakdown of sugar in respiration and those in the synthesis of sugar in photosynthesis are much the same. In both the processes phosphoglyceric acid is formed representing an intermediate product.

4. Respiration is performed by all the living cells of the plant at all times, i.e. it is independent of light and chlorophyll; while photosynthesis is performed only by the green cells, and that, too, only in the presence of sunlight. Although photosynthesis persists only for a limited period, this process is much more vigorous than respiration.

5. Respiration results in a loss of dry weight of the plant due to breaking-down of food materials and the formation of carbon dioxide which escapes from the plant body; but photosynthesis results in a gain in dry weight due to formation of sugar, starch, etc., which accumulate in the plant body.

Fermentation

Fermentation is the incomplete oxidation of sugar into alcohol and carbon dioxide ~~brought about by certain~~ micro-organisms in the absence of oxygen. The change is due to the action of *zymase* (an enzyme complex) secreted by ~~the~~ micro-organisms, and not due to

their direct action on sugar. Under the action of specific enzymes (see p. 306) sugar becomes converted to pyruvic acid. The latter is then reduced to ethyl alcohol (through acetaldehyde) and carbon dioxide by the enzyme *carboxylase*. Fermentation is most readily seen in toddy and also in grape-juice, where sugar is broken up by unicellular yeast plants into alcohol and carbon dioxide, the frothing in the case of toddy being due to the formation of this gas. Fermentation may be defined as an enzyme action on sugar in the absence of free oxygen, splitting it (sugar) into carbon dioxide and alcohol and sometimes organic acids. The process is analogous to anaerobic respiration and may be represented by identical formula —$C_6H_{12}O_6$+Zymase=$2C_2H_5OH$+$2CO_2$+Zymase+Energy (sugar +zymase=alcohol+carbon dioxide+zymase+energy). Common examples of fermentation are: alcoholic fermentation (conversion of sugar into alcohol by yeast), lactic acid fermentation (souring of milk), butyric acid fermentation (rancidity of butter), acetic acid fermentation (manufacture of vinegar from alcohol), etc.

Experiment 34. Fermentation. Experiment on fermentation may be easily carried out with the help of a Kuhne's fermentation vessel (FIG. 40) and the procedure is as follows. Prepare a 5% glucose solution in water and add to it a small quantity of fresh brewers' yeast, or collect a quantity of date-palm juice early in the morning. Completely fill the closed upright tube of the fermentation vessel with this solution or the juice and partially fill the side-tube up to or below the base of the bulb. Warm the solution to about 25°C. and leave the apparatus in a warm place for a few hours. *It will be* seen that a gas collects at the upper end of the closed tube displacing the solution which now accumulates in the bulb of the side-tube and overflows it The evolution of gas continues so long as the sugar in the solution is not exhausted. Then introduce a small piece of caustic potash stick into the fermentation vessel and gently shake it to dissolve the piece, taking care that the gas collected in the closed tube does not escape. Place the fermentation vessel again in the vertical position. Within a few minutes it will be seen that the gas is absorbed by the solution which rises and again fills up the tube. The gas evidently is carbon dioxide evolved during fermentation.

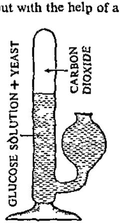


FIG. 40 Kuhne's fermentation vessel (see experiment 34).

Respiration and Fermentation. Both respiration and fermentation are oxidation processes by which energy stored up in carbohydrates and other compounds is set free, and carbon dioxide given out. The two processes depend upon whether free oxygen is available or not, and to what extent oxidation (complete or incomplete) proceeds. Recent researches show that respiration in higher plants takes place in two stages: an anaerobic phase resulting in incomplete oxidation of sugar, and an aerobic phase resulting in complete oxidation of the intermediate products formed in anaerobic respiration, into carbon di-

oxide and water. Fermentation is that type of anaerobic respiration in which alcohol is produced (Palladin). Generally speaking, respiration includes only aerobic respiration; while fermentation is regarded as a synonym for anaerobic respiration. On this basis the distinctions between respiration and fermentation are as follows.

(1) Respiration takes place in the presence of free oxygen; while fermentation takes place in the absence of free oxygen which is derived from rearrangement of molecules of some carbohydrates, and thus fermentation is also known as intramolecular respiration. The initial or anaerobic phase is the same in both the processes.

(2) Respiration takes place in all the living cells of the plant body and at all times in the presence of carbohydrates; while fermentation takes place only in the presence of some easily available carbohydrates such as different sugars under the action of certain microorganisms such as yeast, bacteria, fungi, etc.

(3) In respiration carbohydrates are completely oxidized into carbon dioxide and water; while in fermentation carbohydrates are incompletely oxidized forming carbon dioxide, alcohol and various other products.

(4) Respiration is more efficient than fermentation so far as release of energy is concerned; in respiration a much larger amount of energy is liberated as a result of complete oxidation; while in fermentation much less energy is liberated as a result of incomplete oxidation as may be seen from the following equations:

Respiration — $C_6H_{12}O_6+6O_2=6CO_2+6H_2O+674$ cal.
Fermentation— $C_6H_{12}O_6 = 2C_2H_5OH+2CO_2+28$ cal.

Chapter 11 METABOLISM

Two series of chemical changes or processes are simultaneously going on in a plant cell, one leading finally to the construction or building-up of the protoplasm, and the other to its decomposition or breaking-down. These processes which are constructive on the one hand and destructive on the other are together known as metabolism. Metabolism takes place only in the living cells, and is one of the characteristic signs of life. The processes that lead to the construction of various food materials and other organic compounds and finally of protoplasm are together known as anabolism, and those processes leading to the destruction or breaking-down as catabolism.

Anabolism. The main anabolic or constructive changes are: formation of sugars and other carbohydrates, formation of proteins and

formation of fats and oils. These changes are regarded as anabolic because the protoplasm continually reconstructs itself with these nutritive substances. By anabolism a considerable amount of potential energy is stored in the substances for future use by the protoplasm.

Catabolism. Side by side with anabolism, catabolic or destructive changes or processes are also going on in the living cells of the plant body. The main catabolic processes are: digestion, respiration and fermentation. By these processes complex food substances are gradually broken down into simpler products, e.g. various carbohydrates into glucose, various proteins into amines and amino-acids, and fats and oils into fatty acids and glycerine. The potential energy already stored up in them is released by catabolism into kinetic energy for manifold activities of the protoplasm. Carbon dioxide and water are formed as a result of complete oxidation of glucose in aerobic respiration, and alcohols and organic acids as a result of incomplete oxidation of glucose in anaerobic respiration or fermentation. Amino-acids sometimes result from the decomposition of protoplasm. Besides, the secretory products such as enzymes, vitamins, hormones, cellulose, nectar, etc., are also the results of catabolic processes. Catabolism also results in the formation of many *by-products* in plants. The various waste-products such as tannins, essential oils, gums, resins, etc., belong to this category. These being useless to the protoplasm or even harmful are removed from the sphere of protoplasmic activity, and mostly stored up in special cells, bark, old leaves, heart-wood and glands. In this sense the various kinds of waste products may also be regarded as excretory products. Besides, many other substances such as some of the vegetable (organic) acids, aromatic compounds, anthocyanins, lignin, cutin, etc., are formed in the plant body as a result of catabolic processes.

Chapter 12 GROWTH

The growth of a plant is associated with both constructive and destructive changes. The former lead to the formation of various nutritive substances and the protoplasm, and the latter to their breakdown. The protoplasm assimilates the protein food and increases in bulk (see p. 302); while the carbohydrates are mainly utilized in respiration and in the formation of the cell-wall substance, viz. cellulose. The cells divide and numerous new cells are formed; these increase in size and become fully turgid, and the plant grows as a

whole. Growth is thus a complex vital phenomenon brought about by the protoplasm. *It may be defined as a permanent and irreversible increase in size and form attended by an increase in weight*; sometimes at an early stage of growth a loss in weight is noticed; as, for example, when a potato tuber sprouts it shows a loss of weight in the beginning due to transpiration and respiration. But that is soon made good as new materials begin to be formed by the sprouting shoot. Growth is usually very slow in plants, and is difficult to detect and measure accurately within a short space of time without the help of a suitable instrument. There are certain plants, however, which show very rapid growth, but this growth is confined to certain organs only; as, for instance, the stamens of wheat, young shoots of certain bamboos and tendrils of some *Cucurbitae* which show an average growth in length of about 1 mm. per minute. The growth of a plant, however slow it may be, can be accurately measured with the help of an instrument, called the auxanometer.

Experiment 35. Growth in Length of the Shoot. The auxanometer is an instrument by means of which a small increase in length can be magnified many times. From this total known magnification recorded by the auxanometer the actual length attained by a plant within a certain specified time can be easily calculated. Two types of auxanometer are in common use; the first and the simplest type

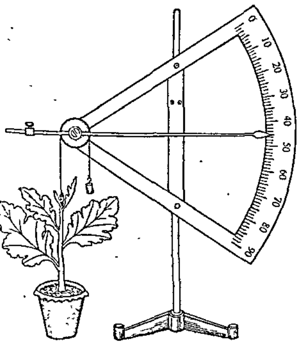


FIG. 41. Arc indicator or lever auxanometer.

is the lever auxanometer or arc indicator (FIG. 41), and the second is the pulley auxanometer or simply auxanometer (FIG. 42). In both the principle is the same.

(*a*) In the lever type there is a movable lever or indicator fixed to a wheel

round which passes a cord. One end of the cord is tied round or gummed to the apex of the stem, and from the other end a small weight is suspended to keep the cord taut. As the stem increases in length the wheel slowly rotates under the weight suspended and the indicator moves down the graduated arc. The growth in length of the plant is thus recorded by the instrument on a magnified scale. From the record thus obtained the actual increase in length of the stem is calculated, for instance, if the lever has traversed a distance of 45 cm. in 24 hours, and the magnification is 90 times, the actual growth in the same period is $\frac{45}{90}$ cm., i.e., 0.5 cm or 5 mm. and, therefore, in 1 hour the actual growth of the plant is $\frac{5}{24}$ *mm*, *i e.* 0.2 *mm*.

(*b*) With the pulley auxanometer a permanent record of growth within a specified time is obtained on a smoked paper which is wrapped round a drum or cylinder. The drum is rotated by means of a clockwork mechanism. A cord with one end attached to the plant is passed round a small wheel, and a small weight suspended from the other end. Round the bigger wheel, which is fixed to the smaller one, passes another cord with two small weights at the two ends. There is a horizontal pointer attached to the cord with the tip in contact with the smoked paper. As growth takes place and the drum rotates, the pointer, being attached to the cord of the bigger wheel, leaves a mark on the paper on a magnified scale. After a period of growth the paper is removed and dipped into varnish, and the smoke or soot becomes fixed on the paper. If growth proceeds continuously a diagonal curve is traced on the paper (FIG 42). If growth ceases a horizontal curve is the result. Magnification being known it is easy to calculate the actual growth within a certain specified time.

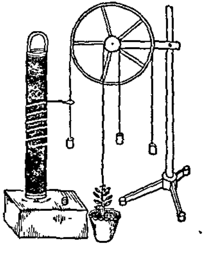


FIG. 42. *A pulley auxanometer.*

Crescograph. The late Sir Jagadish C. Bose constructed a very delicate apparatus known as a crescograph which is an electric device. With the help of this apparatus the growth of a plant can be magnified one thousand to ten thousand times and accurately measured. At this high magnification it has been found possible to measure the progress of growth even in seconds.

Conditions necessary for Growth. Since growth is brought about by the protoplasm the conditions necessary for growth are the same as those that maintain the activity of the protoplasm, as follows:

(1) **Supply of Nutritive Materials.** Growth can only take place when the protoplasm of the growing region is supplied with nutritive materials. The protoplasm assimilates these materials and builds up the body of the plant. Food materials are also a source of energy.

(2) **Supply of Water.** An adequate supply of water is absolutely necessary to maintain the turgidity of the growing cells. Turgidity

is the first step towards growth. The protoplasm can only work when it is saturated with water. An abundant supply of water makes good the loss due to transpiration. It is a fact, however, that only a small quantity is required for actual growth.

(3) **Supply of Oxygen.** Supply of free oxygen is indispensable for the respiration of all living cells. Respiration is an oxidation process by which the *potential* energy stored in the food is released in the form of *kinetic* energy and made use of by the protoplasm for its manifold activities.

(4) **Suitable Temperature.** The protoplasm requires a suitable temperature for its activities; at a low temperature it ceases to perform its functions or does so very slowly; while a temperature of 45° to 50°C. coagulates and kills the protoplasm. The protoplasm is maintained in a healthy condition within certain degrees of temperature. This is said to be due to the **thermotonic** effect of temperature. The optimum temperature ordinarily averages from 28° to 30° C., and the minimum lies at about 4°C.

(5) **Light.** Light is not absolutely necessary for the initial stages of growth. In fact, plants grow more rapidly in the dark than in the light. Although light has a retarding effect on growth, the protoplasm is maintained in a healthy condition and the plant becomes sturdy with normal development of the stem and the green leaves when there is a certain intensity of light. Moreover, as we have

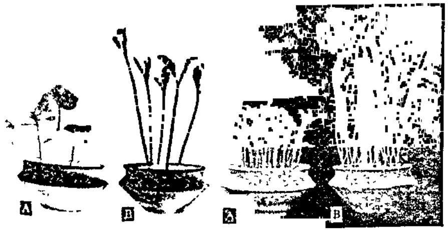


FIG. 43. Effect of light and darkness on growth of seedlings. *Left*, gourd seedlings; *right*, gram seedlings; *A*, grown in light; *B*, grown in darkness.

already learnt, stomata remain open and chloroplasts function normally preparing food substances only in the presence of light. All this is said to be due to the phototonic or stimulating effect of light. Continued absence of light is very harmful to plant. Plants grown in the dark or in very weak light have weak soft and slender stems

with elongated internodes, are pale-green or pale-yellow in colour and sickly in appearance, and seldom produce flowers and fruits; leaves of such plants are small, pale-yellow in colour and often remain undeveloped; and their roots are seen to be poorly developed. Plants showing these characteristics are said to be **etiolated.** The relative length of day and night has a profound influence on the production of flowers and fruits (see photoperiodism, p. 326). The effect of particular rays of light on the growth of the plant can be easily seen when a pot plant is grown within a double-walled bell-jar which has been filled up with red, yellow, green or any other solution (see also p 286). The effect of unilateral light on growth and movements is discussed on pp. 327 and 330.

(6) **Force of Gravity.** This factor determines the direction of growth of particular organs of the plant body (see p. 331). The root grows towards the force of gravity, and the stem away from it.

Phases of Growth (FIG. 45). Growth does not take place throughout the whole length of the plant body, but is localized in special regions called *meristems* which may be apical, lateral, or intercalary. The growth in length is due to gradual enlargement and elongation of the cells of the apical meristems (root-apex and stem-apex) and in dicotyledons and gymnosperms the growth in thickness is due to the activity of the lateral meristems, i.e. interfascicular cambium, fascicular cambium and cork-cambium. If the history of growth of any organ of a plant be followed three phases can be recognized in it.

(1) **The Formative Phase.** This is restricted to the apical meristem of the root and the stem. The cells of this region are constantly dividing and multiplying in number. They are characterized by abundant protoplasm, a large nucleus and a thin cellulose wall.

(2) **The Phase of Elongation.** This lies immediately behind the formative phase. The cells no longer divide in this phase, but increase in size; they begin to enlarge and elongate until they reach their maximum dimension. In the root this phase occupies a length of a few millimetres, and in the stem a few centimetres. In some of the climbers it may occupy a much longer space than this.

(3) **The Phase of Maturation.** This phase lies further back. Here the cells have already reached their permanent size; the thickening of the cell-wall takes place in this phase.

Grand Period of Growth. Every organ of the plant body, in fact every cell that the organ is composed of, shows a variation in the rate of its growth. The growth is at first slow, then it accelerates until a maximum is attained, then it falls off rather quickly, and gradually slows down until it comes to a standstill. This growth of an organ or a cell or the plant as a whole extending over the whole period is called the **grand period of growth.** Within the grand period

variations in growth occur due to external and other causes. There is thus the *diurnal variation of growth*. Light inhibits growth, and too intense light even checks it altogether. Thus plants grow quicker

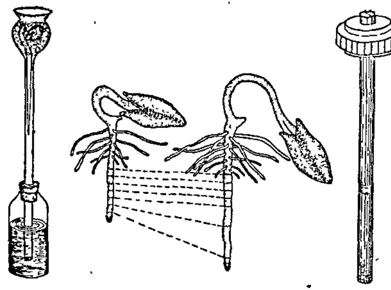


FIG. 44 FIG. 45 FIG. 46

FIG. 44. Measurement of growth of root. FIG. 45. Phases of growth of root. FIG. 46. A space marker wheel.

during the night than during the day. There is also *seasonal variation of growth*; during winter the growth of many plants is checked or becomes very slow, but during spring growth proceeds rapidly.

Experiment 36. Distribution and Rate of Growth. (*a*) **Root.** With the help of a space marker wheel (FIG. 46) mark the root of a germinating seed with transverse lines equidistant from each other. Waterproof Indian ink should be used for the purpose. The germinating seed is then packed in wet cotton and placed in the bulb of a thistle funnel which is allowed to stand in a bottle containing water. The stem of the funnel is covered with black paper to prevent curvature of the root owing to light. After a few days it is seen that the lines at a little distance behind the tip become widely separated from each other, while those higher up and at the tip remain more or less intact. This evidently shows that the growth is fastest behind apex. The *rate of growth* may easily be measured from day to day with the help of a scale. (*b*) **Stem.** The distribution of growth in the stem is also found out in a similar way. For this the thistle funnel need not be used. The stem shows the same phases of growth as the root. The rate of growth of the stem may be accurately measured with the help of an auxanometer. (*c*) **Leaf.** The distribution of growth of a flat organ like the leaf may be found out with the help of an instrument called the space marker disc.

Hormones. It is now definitely known that certain synthetic products formed in very minute quantities as a result of metabolism inside the plant body have a profound influence on the *growth* of the plant organs and on the various kinds of *tropic movements* exhibited by

such organs; they also have a marked effect on certain physiological processes They are known as the **hormones** or **phytohormones** or **growth hormones.** Of the various kinds of hormones discovered to date **auxins** are known best so far as their occurrence, composition and actions are concerned. They are formed in one part of the plant body, chiefly in the apical meristem, and transported from there to another part to produce a particular physiological effect there. Their movement is strictly longitudinal, normally from the apex downwards. Upward translocation is also possible through transpiration current. The presence of hormones was first demonstrated by experimental methods.[1] It has now been possible to extract them from plants by appropriate chemical methods. At low concentration they stimulate growth, while at high concentration they retard growth. Auxins cause the formation of roots in stem-cuttings and in grafting. They are responsible for seed germination, seedling growth and growth of plant organs; they also stimulate cell divisions and cell elongation, and influence certain physiological processes; besides, the role of hormones in tropic responses has now been well established. Thus *phototropism* and *geotropism* are now explained on a hormonal basis. In the case of phototropism hormones in course of

[1] The term hormone was first used by Starling in 1906 in connexion with certain secretions in the animal body. In the case of plants the action of hormones (auxins) was first demonstrated on oat coleoptile by Boyes-Jensen (1910), Stark (1920) and more elaborately by Went and Thimann (1925 and later). The tip of the oat coleoptile was cut off some millimetres behind the apex; evidently the growth of the coleoptile was checked. But when the decapitated tip was affixed on the cut surface it was found that growth was resumed at almost the normal rate. Evidently the tip contained something which when transmitted to

happened. Evidently something was transmitted from the cut-off tip to the agar medium and thence to the main coleoptile. That something is now known to be an auxin. Further experiments were performed. Another agar block treated in in the same way was next placed on the cut surface on one side and it was seen that growth was more rapid on this side, resulting in a curvature of the coleoptile Evidently the auxin accelerated growth of this side. By 1934 at least three

acid, naphthalene-acetic acid, etc.

their downward movement from the apex accumulate in the shaded side which then grows more rapidly than the illuminated side, and thus a phototropic curvature takes place, i.e. the shoot bends towards the light. In the case of geotropism hormones accumulate on the lower side of the horizontally placed shoot. Thus the growth of this side is stimulated, and the stem bends upwards. In the horizontally placed root hormones similarly accumulate on the lower side but the root reacts in a different way. It is probable that the growth of the root is stimulated by lower concentration of the hormones. Therefore, the particular concentration that has stimulated the growth of the stem checks the growth of the root on its lower side. As a consequence the root bends downwards. Hormones responsible for the development of the root, stem, leaf, flower, fruit, etc., have also been discovered; for example, rhizocaline made in the leaf is necessary for root formation, caulocaline formed in the root is necessary for stem elongation, phyllocaline formed in the cotyledon is necessary for leaf growth, florigen formed in the leaf induces flower formation, wound hormone (traumatic acid) is necessary for the healing of wounds, etc.

Vitamins. Vitamins are a group of organic substances which have proved to be invaluable in effecting normal growth and development of the body, and also in preventing or curing certain deficiency diseases such as scurvy, beriberi, rickets, malnutrition, loss of appetite, poor physical growth, eye infection, nervous breakdown, etc., caused by the absence of the vitamins in the food or their faulty absorption due to intestinal troubles. For some centuries scurvy (livid spots on the skin and general debility) was a dreaded disease among sailors. Vasco da Gama lost 100 sailors on this account during his voyage round the Cape of Good Hope in 1498. Lind's discovery in 1757 of the value of *Citrus* fruits (oranges and lemons) and green vegetables in the treatment of scurvy, as emphasized in his book *A Treatise on the Scurvy*, came very opportunely. Captain Cook who included fruits and vegetables in the rations for sailors lost none during his voyage to Australia in 1772. About the year 1793 it was definitely found that the use of orange or lemon juice completely dispelled scurvy from the navy. Evidently it contained something (now known to be vitamin C) which was responsible for the prevention and cure of the disease. It was only from the year 1906 that investigations on vitamins were made from the biological standpoint. In 1910 Hopkin's work in England on rats fed on pure foodstuff and that with added fresh milk or fresh fruit juice definitely proved the importance of vitamins for healthy growth. Up till now several vitamins have been discovered and their value established. They are now regarded as protective foods. Vitamins are required only in minute quantities for a particular effect, and are used up in

the metabolic processes. They are mostly formed by plants and stored up in their different organs. Plants, therefore, are the main sources of vitamins for animals including human beings. It has now been possible to synthesize some of the vitamins artificially, particularly vitamins C and D, on a commercial scale. Some common and important vitamins are as follows.

Vitamin A is a growth-promoting and anti-infective vitamin; soluble in fats and oils (sparingly soluble in water); fairly resistant to heat. It is especially good for children; helps healthy growth and physical fitness; builds resistance to bacterial infections of the lungs and the intestines; helps normal functioning of the different organs of the body; prevents many eye-diseases, particularly night-blindness; and cures skin-diseases and nervous weakness. Carotene of plants is the source of this vitamin, and animals can synthesize vitamin A in their body by taking food containing carotene. Excess of vitamin A is stored in the liver and utilized when deficiency occurs. Main sources of this vitamin are carrot, green leafy vegetables, cereals (particularly in their pericarp), pulses, many fruits (particularly yellow ones, e.g. tomato, mango, orange, apple, papaw, etc.), fish-liver oils (e.g. cod-liver oil and halibut-liver oil), liver of mammals, milk, butter, egg-yolk, etc.

Vitamin B consists of a group of closely allied vitamins, commonly called *vitamin B complex*. The important members of this group are the following. **Vitamin B_1** (or thiamine—an anti-beriberi vitamin) is soluble in water and, therefore, easily removed with rice-broth; not easily destroyed by heat. It prevents and cures beriberi, heart disease and some forms of anaemia. Beriberi was for a long time a dreaded disease in the rice-eating countries of India, Malaya, China and Japan. Polished rice (evidently something, now known to be this vitamin, removed from its pericarp) was found to be the cause of this disease which resulted in immense suffering and often innumerable deaths. **Vitamin B_2** (or riboflavin) is slightly soluble in water; relatively stable to heat but destroyed by light. It promotes growth and removes digestive troubles; prevents and cures nervous and general debility, low vitality and some form of eye-disease. **Vitamin B_6** (or pyridoxine) is soluble in water; resistant to heat. It has clinical value in treating certain nervous and muscular disorders and certain types of anaemia. **Vitamin B_{12}** is sparingly soluble in water; resistant to very high temperature. It cures some of the symptoms of pernicious anaemia. **Nicotinic Acid** is soluble in water; resistant to very high temperature. It prevents pellagra (a kind of skin disease), persistent diarrhœa and mental disease like insanity. **Folic Acid** is sparingly soluble in water. It is responsive to pernicious anaemia. **Biotin** (vitamin H) is soluble in water; resistant to heat. It cures scaling-off of the skin, muscular pain, distress of the heart and loss of appetite. Vitamin B complex is very widely distributed

and occurs in nearly all natural foods; rich sources, however, are dried yeast, whole grains (unpolished), pulses, most vegetables (particularly green ones like spinach, lettuce and cabbage), many fruits (e.g. tomato, orange, banana, apple, etc.), nuts, milk, cheese, egg-yolk, meat, liver, fish, etc.

Vitamin C (or ascorbic acid—an anti-scurvy vitamin) is soluble in water; sensitive to heat and, therefore, lost by cooking. It prevents scurvy, mental depression, swelling and bleeding of gums and degeneration of teeth. It is found in most fresh fruits (particularly orange, lemon, pummelo, tomato, pineapple, guava, papaw, etc.), green vegetables (e.g. spinach, lettuce, cabbage, etc.), sprouted pulses and cereals, and in milk.

Vitamin D (or calciferol—an anti-ricket vitamin) is soluble in fats and oils; cannot stand strong light; otherwise sufficiently stable. Its deficiency causes rickets and dental caries in children, and osteomalacia (softening of bones in adults). Absence of this vitamin inhibits proper absorption of calcium and phosphate. It is commonly associated with vitamin A in the same foodstuff, and found in dried yeast, milk, butter, egg-yolk, fish and fish-liver oils. Vitamin D can also be produced in the human body by the action of ultra-violet ray (from sunlight or electricity) on the skin.

Vitamin E (or anti-sterility vitamin) is soluble in fats and oils; resistant to heat and light but destroyed by ultra-violet ray. Its deficiency causes sterility in animals (not yet definitely proved in the case of human beings), degeneration of muscles, and falling-out of hairs. It is found in green vegetables, germinating grains, wheat embryo, milk, egg-yolk, meat, etc.

Vitamin K is fat-soluble. Its deficiency causes a lowering of prothrombin value of the blood, i.e. does not help proper blood-clotting in wounds and cuts. It is found only in plants, particularly in green vegetables and fresh fruits, and also in yeast.

Vernalization and Photoperiodism. The influence of temperature and of day-length on the sexual reproduction of plants, particularly in the case of annuals and biennials, has been lately investigated. The outcome of these investigations is the discovery of very important phenomena known as vernalization and photoperiodism. It is interesting to note that some plants, mostly of the temperate regions, require a period of low temperature before flowering takes place. But for this condition the plants would not produce flowers. In fact, if the low temperature requirement (1° to 10°C.) of the plants be artificially supplied to the soaked seeds undergoing germination, it is seen that the plants flower much earlier. This method of inducing earlier flowering by pre-treatment of the seeds with very low temperature was developed in Russia by Lysenko, and is known

[illegible]

in the year the soil remains ice-bound and unfit for any kind of cultivation;

during the remaining two months only early maturing crops can be grown.

The influence of day-length on reproduction was studied in America by Garner and Allard. According to them some plants require a day-length longer than 12 hours for flowering, while others require less than 12 hours for this purpose. The former are known as long-day plants and the latter as short-day plants. There are also some plants which are day-neutral as they flower at any day-length. The relation of the time of flowering to the daily length of the period of illumination is known as **photoperiodism**. Photoperiodism has helped in the control of flowering of a large number of agricultural and horticultural plants. Artificial shortening of day-length by shading, or lengthening of the day-length by electric illumination has induced plants to flower earlier than the normal ones. [illegible]

[illegible] required day-length is not available under natural conditions. Flowering of *various annual and biennial plants at different seasons of the year is mainly due* to the seasonal day-length. In agricultural research this is of particular benefit as by artificial control of day-length (daily illumination) two crop varieties which normally flower at different seasons can be made to flower simultaneously so that cross-pollination for the purpose of crop-improvement can be effected.

Chapter 13 MOVEMENTS

Living beings are distinguished from non-living ones by *their power* of movement. Protoplasm is sensitive to various external agencies such as heat, light, electricity, gravity, certain chemicals, etc., which act as stimuli and plants or plant organs often respond to such stimuli by movement of their body in a particular direction taking up thereby [illegible] particular [illegible] them is sp[illegible] kind of mo[illegible] this movement it can adjust itself according to the conditions of the environment.

Conditions necessary for Movements. (1) Water. An *adequate supply* [illegible]

[illegible] cerned. Respiration releases energy for work. **(4) Hormones.** Hormones (see pp. 321-3) are now known to have a profound influence on

growth and certain kinds of movement. (5) Non-fatigue. Continued stimulation brings about fatigue. No response can be evoked from a fatigued organ or tissue.

Kinds of Movements. Plants show different kinds of movements, and these may be broadly classified as (I) movements of locomotion and (II) movements of curvature.

I. MOVEMENTS OF LOCOMOTION

Movements of protoplasm within the cell, free movements of naked masses of protoplasm and those of unicellular or multicellular organs and entire organisms are expressed as movements of locomotion. These movements may again be (1) spontaneous (or autonomic) and (2) induced (or paratonic).

1. Spontaneous Movements. Spontaneous movement is the movement of the protoplasm or minute free organs or entire organisms *of their own accord*, that is, without the influence of external factors; it may be due to some internal causes, not clearly understood. Common instances are: ciliary movement of free ciliate protoplasmic bodies; amoeboid movement of free non-ciliate protoplasmic masses; rotation or circulation of protoplasm within the cell; oscillating movement of *Oscillatoria* (see FIG. V/2); and brisk movements of many unicellular algae like desmids and diatoms.

2. Induced Movements. Movements of minute free organs or entire organisms—unicellular or multicellular—may be induced by some external factors which may be in the nature of certain chemical substances, light and heat. These factors act as stimuli. Movements thus influenced by external stimuli are otherwise called taxisms, or tactic movements, and depending on the nature of the stimulus taxisms may be (1) chemotaxis when influenced by chemical substances, (2) phototaxis when influenced by light, and (3) thermotaxis when influenced by temperature.

(1) **Chemotaxis.** Chemotaxis is the movement of free organs or organisms brought about by the presence of certain chemical sub-

of many 'flowerless' plants. Thus in mosses cane-sugar is secreted by the archegonium for the purpose of attracting the antherozoids towards it. In ferns malic acid is secreted for the same purpose.

(2) **Phototaxis.** Phototaxis is similarly the movement of free organs or organisms in response to the stimulation of light. Algae afford very good examples of phototaxis. They move towards the source of weak light being attracted by it. Very strong light, however, repels them; they turn away from it. Another striking example

of phototaxis is afforded by the chloroplasts of the leaf. Too intense light decomposes chlorophyll and, therefore, under this condition the chloroplasts arrange themselves one over the other alongside the lateral walls of the palisade cells of the leaf. This arrangement or movement of the chloroplasts is called apostrophe. In subdued light, however, they arrange themselves alongside the outer and inner walls. This arrangement or movement of the chloroplasts is called **epistrophe.**

(3) **Thermotaxis.** Thermotaxis is similarly the movement of free organs or organisms in response to the stimulation of heat. If there is a difference in temperature they are seen to move towards the warmer side. Protoplasm shows more rapid rotation or circulation if the tissue be gently warmed. Thus if a section from a *Vallisneria* leaf be slightly warmed over a burning match-stick and then examined under the microscope the protoplasm is seen to rotate more rapidly.

II. MOVEMENTS OF CURVATURE

Higher plants being fixed to the ground are incapable of any locomotion. Some of their organs, however, show different kinds of movement. Thus these organs may move and change their position or direction by means of curvature. As the organs move they take up an advantageous position in order to perform their functions more effectively. Movements of curvature may be mechanical or vital. Vital movements are broadly of two kinds: spontaneous (or autonomic) and induced (or paratonic).

1. **Mechanical Movements.** Mechanical movements are exhibited by certain non-living organs of plants, e.g. bursting of explosive fruits (see p. 126), bursting of sporangia of ferns (see FIG. V/146) and some other structures. Some fruits burst suddenly when they dry up, e.g. *Phlox*—a garden herb, *Barleria*, camel's foot climber (*Bauhinia vahlii*; see FIG. I/176), *Andrographis*, etc., and others do the same when they absorb water, e.g. *Ruellia* (see FIG. I/175). The dry long awn of certain grasses—wild oat, for example—coming in contact with water begins to twist and roll. The elaters of *Equisetum* spore are very hygroscopic; when the air is moist they roll up spirally round the spore, and when the air is dry they uncoil and stand out

2. **Spontaneous Movements.** Spontaneous movements are movements of certain living organs of plants *of their own accord*, that is, without the influence of external factors. Such movements may be of two kinds: (1) movement of variation and (2) movement of growth.

(1) **Movement of Variation.** The movement of variation is the movement of *mature* organs due to *variation in the turgidity* of the cells making up those organs. It is fairly rapid. The spontaneous movement of variation is rather rare: in the majority of plants the movement of cellular organs is induced by external factors. The spontaneous movement is, however, very remarkably exhibited by the *pulsation*, i.e. rising and falling of the two lateral leaflets of Indian telegraph plant (*Desmodium gyrans*; FIG. 47), the terminal leaflet, however, remaining fixed in its position. Normally these two leaflets move up and down from morning till evening, i.e. so long as sunlight is available; but sometimes they continue to move till late hours at night depending on the energy that they have conserved from the sunlight during the daytime.

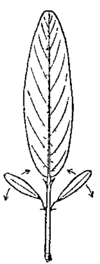


FIG. 47. A leaf of Indian telegraph plant.

Turgor Movements. These are movements exhibited by certain plant organs due to changes in the turgidity of certain cells of these organs, commonly the pulvinus in the case of the leaf. Turgor movements are often rapid and may occur again and again. They may be spontaneous (movement of variation), as exhibited by Indian telegraph plant, or may be induced by contact, light, heat, etc., as exhibited by sensitive plant, sensitive wood-sorrel, carambola (*Averrhoa*; B. KAMRANGA; H. KAMRAKH), most species of *Leguminosae*, some species of wood-sorrel (*Oxalis*), and by the opening and closing of the stomata.

(2) **Movement of Growth.** The movement of growth is the movement of *growing* organs *due to unequal growth* on different sides of those organs. It is very slow. This kind of movement is seen in some trailers and creepers. In them at one time the growth is comparatively rapid on one side of the stem and then it passes on to the opposite side. The stem tip then moves from one side to the other. In such a case the stem, as it elongates, moves in a zigzag course. Movement of this kind is known as (1) nutation. If the growth passes regularly around the stem, it then moves in such a way as to form a spiral, as in tendrils and twiners. Movement of this kind is said to be (2) circumnutation. Another kind of growth movement is exhibited by most of the young leaves. In them at the initial stage the growth is more rapid on the undersurface and, therefore, they remain rolled or folded on the upper surface. This kind of growth movement is called (3) **hyponasty**. Later due to more rapid growth on the upper surface the leaves open and become flat and straight. This is called (4) **epinasty**. A striking example is afforded by fern leaves (see FIG. V/143). Here the leaves are at first closely coiled due to hyponastic growth, and later they uncoil and become straight due to epinastic growth.

3. **Induced Movements.** Movements of certain living organs of plants may be induced by external factors which act as stimuli. Induced movements are broadly of two kinds: (a) tropic and (b) nastic. The stimuli may be in the nature of (1) contact, (2) light, (3) gravity, (4) temperature, (5) certain chemical substances, and (6) moisture.

(a) **Tropic Movements or Tropisms.** Tropic movements of plant organs are, like taxisms, always directive, i.e. the direction of movement is determined by the direction from which the stimulus is applied, and the organs move either towards the source of the stimulus or away from it. The nature of the stimuli such as (1) contact, (2) light, etc., as stated above, and the corresponding tropic movements are as follows:

(1) **Contact with a Foreign Body.** The movement of an organ stimulated by contact with a solid object is called **haptotropism** or **thigmotropism**. Twining stems and tendrils are good examples of haptotropism. These organs are sensitive to contact with a foreign body but the reaction is rather slow and, therefore, the contact must be of long duration to bring about the movement. Some tendrils, however, respond very quickly, often within a few minutes. When such organs come in contact with any support or any hard object the growth of the contact side is checked, while the other side continues to grow. The result is that the organs slowly coil round that object. This is a mechanism for climbing. Some climbers move clockwise, e.g. white yam (*Dioscorea alata*); while others anticlockwise, e.g. wild yam (*D. bulbifera*). If the direction be artificially altered, growth becomes arrested. Haptotropism is also exhibited by the tendrillar leaf-apex of glory lily (*Gloriosa*) and the petiole of pitcher plant (*Nepenthes*), garden nasturtium and virgin's bower (*Clematis*).

(2) **Light.** The movement of plant organs as determined by the direction of incidence of rays is called **heliotropism or phototropism.** Some organs grow towards the light and are said to be *positively heliotropic*, as the shoot; while others grow away from it and are said to be *negatively heliotropic*, as the root. Dorsiventral organs such as leaves, runners, etc., grow at right angles to the direction of incidence of rays so that their upper surface is exposed to light; such organs are said to be *diaheliotropic*. Positive heliotropism is very noticeable in plants, particularly the seedlings, when these are grown in a closed room or box (**heliotropic chamber**; FIG 48) with one open window on one side. They all tend to grow towards the window i e. towards the source of light, and in the case of the box they ultimately come out through it. The cause of phototropic curvature is now explained on the basis of *hormones* (see pp. 321-3). The effect of this unilateral light may be eliminated by placing a pot plant on a **clinostat** (FIG. 50) in the vertical direction and rotating it. The plant is seen to grow vertically upwards and not to bend

towards the window. The flower-stalk of groundnut (*Arachis hypogaea*; FIG. 49) grows towards light, but after pollination it becomes negatively heliotropic and positively geotropic like the root. The stalk bends down and quickly elongates pushing the fertilized ovary into the ground where gradually the ovary ripens into a pod (fruit). It is also seen, as in *Eucalyptus*, that the edge of the leaf is turned towards intense light and when the light is diffuse the surface is exposed to it.

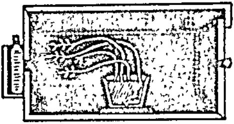


FIG. 48. Heliotropic chamber.

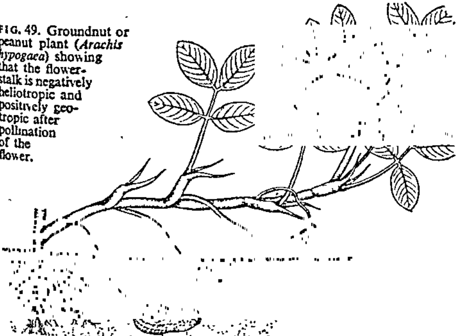


FIG. 49. Groundnut or peanut plant (*Arachis hypogaea*) showing that the flower-stalk is negatively heliotropic and positively geotropic after pollination of the flower.

from it. The former is, therefore, said to be positively geotropic and the latter *negatively geotropic*. The lateral roots and the branches usually grow at right angles to the force of gravity and are said to be *diageotropic*. That the direction of growth is determined by the stimulating action of the force of gravity is clearly seen in a seedling which has been placed in a horizontal position away from light.

Both the stem and the root undergo curvature in their growing region behind the apex, passing through an angle of 90°; the root curves and grows vertically downwards, and so does the stem upwards. It is the very tip of the root, for a distance of 1 to a few mm. in length, that is sensitive to this stimulus; this is the region of cell division (see FIG. I/3). The actual bending, however, takes place some distance behind the tip in the region of elongation. If the tip of the root be decapitated, no bending takes place. Besides, it is seen that the root of a germinating seed can, under the force of gravity, grow downwards even through mercury overcoming considerable pressure. Further, it has been found possible with the help of a *clinostat* (FIG. 50) to eliminate the effect of geotropic stimulus on the root and the shoot by introducing a centrifugal force. This is done by rotating the seedling in a horizontal plane and thus subjecting all sides of the growing and sensitive regions to this force. Under this condition the force of gravity cannot act on any definite part and, therefore, no geotropic movement becomes possible. The cause of geotropic curvature is now explained on the basis of *hormones* (see pp. 321-3).

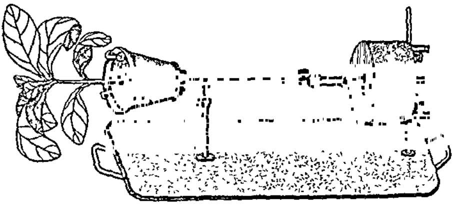


FIG. 50. Clinostat in the horizontal position to eliminate the effect of force of gravity.

Experiment 37. Geotropism. A clinostat (FIG. 50) may be used to demonstrate geotropism. This is an instrument by which the *effect* of lateral light and the force of gravity on an organ of a plant—root or stem—can be eliminated. It consists of a rod with a disc mounted on it, to which a small pot plant may be attached, and a clockwork mechanism for rotating the rod and the disc. The clinostat works slowly—its rotation being ordinarily 1/4th to 4 turns per hour. A plant, preferably a pot plant, may be fixed in the clinostat in any position—vertical, horizontal or at an angle—and made to rotate by clockwork mechanism in the clinostat. When the plant is horizontal, the root and the stem grow horizontally, instead of the root curving downwards and the stem upwards. This is due to the fact that all sides of the growing axes are in turn directed downwards,

upwards and sideways so that the force of gravity cannot act on any definite position. This results in the effect of the force being eliminated altogether. The root and the stem cannot, therefore, bend. If, however, the plant be fixed in the vertical position and the clinostat rotated, it is seen that the plant grows in the vertical direction—the root downwards and the stem upwards.

(4) **Temperature.** The movement or curving of an organ of a plant in response to the stimulus of heat or cold is called **thermotropism.** If a closed box containing seedlings be warmed on one side, it is seen that they curve towards the warm side.

(5) **Chemical Substances.** The movement induced by the presence of certain chemical substances is spoken of as **chemotropism.** The tentacles of sundew respond to various nitrogenous substances placed on its leaf. Thus a drop of soluble protein or a bit of raw meat induces movement only after a portion of it has been absorbed. On absorption the protoplasm gets stimulated and it sends a motor impulse to the surrounding tentacles which bend down on the protein or meat from all sides. The pollen-tube grows towards the ovule being stimulated by the sugary substance secreted by the stigma, the style and the ovary. Sucking roots of parasites and hyphae of parasitic fungi penetrate into the tissue of the host plant in response to the stimulus of certain chemical substances contained in it. Similarly, respiratory roots of many plants growing in estuaries curve upwards from the soil into the air, that is, towards the source of oxygen which stimulates them (see FIGS. IV/2-3).

(6) **Moisture.** The movement of an organ in response to the stimulus of moisture is known as **hydrotropism.** Roots are sensitive to variations in the amount of moisture. They show a tendency to grow towards the source of moisture, and are said to be *positively hydrotropic.* It is seen that roots of seedlings growing in a hanging basket made of wire-netting and filled with moist sawdust at first project downwards coming out of the basket under the influence of the force of gravity, but they soon turn back in response to the stimulus of moisture (moist sawdust of the basket) and pass again into the basket having formed loops.

FIG. 51. Experiment on hydrotropism.

Experiment 38. Hydrotropism. A porous clay funnel, covered around with a filter paper, is placed on a wide-mouthed glass bottle (or hyacinth glass) filled with water, as shown in FIG. 51. The filter paper is thus kept moist. The porous funnel is filled with dry sawdust and the soaked seeds arranged in a circle, each near a pore. It is necessary to add a few drops of water now and then to the seeds to help their germination. As they germinate it will be seen that the roots, instead of going vertically downwards in

response to the force of gravity, pass out through the pores towards the moist filter paper, and grow downwards alongside the paper into the bottle. Roots thus show movements towards moisture, or, in other words, they are positively hydrotropic.

(*b*) **Nastic Movements or Nasties.** Like tropisms nastic movements of plant organs are induced by stimuli such as contact, light and heat, but these movements are not directive, i.e. the direction of movement in such cases is not determined by the direction from which the stimulus is applied, or, in other words, from whichever direction the stimulus acts it equally affects all parts of the organs, and they always move in the same way and in the same direction. Their direction is largely determined by the structure or anatomy of the organs concerned. Nastic movements are mostly exhibited by flat dorsiventral organs like leaves and petals. The following kinds of nasties are common:

(1) **Seismonasty.** The movement brought about by mechanical stimuli such as contact with a foreign body, poking with any hard object, drops of rain, a gust of wind, etc., is called **seismonasty.** Movements of the leaves (leaflets) of sensitive plant (*Mimosa pudica*; FIG. 53), sensitive wood-sorrel (*Biophytum sensitivum*; FIG. 52), *Neptunia*,

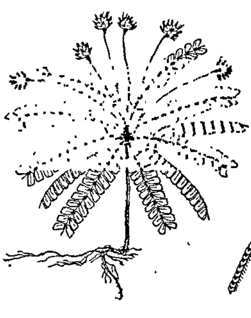


FIG. 52.

FIG. 53.

FIG. 52. Sensitive wood-sorrel (*Biophytum sensitivum*).
FIG. 53. Sensitive plant (*Mimosa pudica*).

carambola (*Averrhoa*), etc., are familiar examples. Leaflets of such plants close up when touched. It is also to be noted that the degree of movement varies according to the intensity of the stimulus

applied; for example, when the leaf-apex of the sensitive plant is lightly touched, only a few pairs of leaflets close up; when rather roughly touched or pinched. all the leaflets react in the same way from the apex downwards; and when roughly handled, all the leaflets close up simultaneously and the leaf as a whole droops. Venus' fly-trap (*Dionaea*; see FIG. 28) is another very interesting example. The two lobes of the leaf of this plant are each provided with three hairs which are extremely sensitive to touch, and in contact with a foreign body, particularly a flying insect, the two lobes close up suddenly. In *Bignonia*, *Mimulus* and *Martynia* the two stigmatic lobes close up when touched or when pollen grains fall on them In the sunflower family (*Compositae*) and China rose family (*Malvaceae*) it is seen that the stigmas bend down and touch the anthers to achieve self-pollination, in case cross-pollination fails. In barberry (*Berberis*), purslane (*Portulaca*), prickly pear (*Opuntia*), etc., the stamens are sensitive, and when touched by an insect they spring violently, strike the insect and dust it with pollen grains.

[illegible]

e.g. noon flower (*Pentapetes*). Some flowers open in weak light in the morning but with the increasing intensity of light as the day advances they close up, e.g. garden *Portulaca*. Some flowers open at night, that is, in darkness but close up at daybreak, e g. night-blooming cacti (*Cereus* and *Phyllocactus*). Stomata open when light appears but close up again when light fails.

(3) **Thermonasty.** The movement induced by variations in the [illegible]

and also of *Oxalis*. When the temperature rises high or falls low the leaves close up, and at optimum temperature they open.

(4) **Nyctinasty.** *The movement induced by alternation of day and night* is called **nyctinasty** (or nyctitropism) or **sleep movement**. Leaves and flowers, particularly the former, are markedly affected by nyctinasty. Nyctinasty is effected by both the factors (light and temperature) acting simulataneously but always more so by light. This kind of movement is most remarkably exhibited by *Leguminosae*. Leaflets of these plants close up and often the leaf as a whole droops in the evening when the light fails, and they open up again when the light appears in the morning. A few other plants like *Chenopodium*, carambola (*Averrhoa*), etc., also show the same phenomenon. Leaflets normally fold on their upper surface, and by doing so excessive radiation of heat is prevented during the night. Movement of this nature is due to difference in the turgidity of the cells of the pulvinus at the base of the leaf and the leaflets. Among the flowers showing

nyctinasty mention may be made of *Gerbera* (a garden herb), *Portulaca* (wild or garden variety), etc.

The various kinds of movements that have already been described are scheduled below.

MOVEMENTS IN PLANTS

- Movements of Locomotion
  - *spontaneous*
    - ciliary
    - amoeboid
    - cyclosis
      - *rotation*
      - circulation
  - *induced*
    - tactic
      - chemotaxis
      - phototaxis
      - thermotaxis
- Movements of Curvature
  - *mechanical*
    - hygroscopic movements
  - *vital*
    - *spontaneous*
      - movements of variation
      - movements of growth
        - nutation
        - hyponasty
        - epinasty
    - *induced*
      - nastic
        - seismonasty
        - photonasty
        - thermonasty
        - nyctinasty
      - tropic
        - haptotropism
        - phototropism
        - geotropism
        - thermotropism
        - chemotropism
        - hydrotropism

Chapter 14 REPRODUCTION

Since the life of an individual plant is limited in duration it has developed certain mechanisms by which it can reproduce itself in order to continue the perpetuation of the species and also to multiply in number. The following are the principal methods of reproduction: vegetative, asexual and sexual.

(1) Vegetative Reproduction

A. NATURAL METHODS OF PROPAGATION

In any of these methods a portion gets detached from the body of

the mother plant, and this detached portion embarks on a new career under suitable conditions. Gradually it grows up into a new independent plant. The methods by which vegetative propagation takes place are many and varied.

(1) **Budding.** In the case of yeast (see FIG. II/24) one or more tiny outgrowths appear on one or more sides of the vegetative cell immersed in sugar solution. Soon these outgrowths get detached from the mother cell and form new individuals. This method of outgrowth formation is known as budding. Often budding continues one after the other so that finally a chain of cells is formed. All the individual cells of the chain separate from one another and form new yeast plants.

(2) **Gemmae.** In some mosses and liverworts special bodies known as gemmae (see FIGS. V/95 & 97) develop on the leaf, branch or thallus for the purpose of vegetative propagation.

(3) **Leaf-tip.** There are certain ferns, commonly called 'walking' ferns (e.g. *Adiantum caudatum*, *A. lunulatum* and *Polypodium flagelliferum*), which propagate vegetatively by their leaf-tip (FIG. 54). As the leaf bows down to the ground the tip strikes roots and forms a bud. This bud grows into a new independent fern plant. Ferns normally, however, reproduce vegetatively by their rhizome.

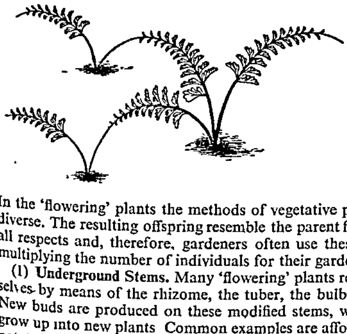


FIG. 54. Walking fern (*Adiantum caudatum*).

In the 'flowering' plants the methods of vegetative propagation are diverse. The resulting offspring resemble the parent forms in almost all respects and, therefore, gardeners often use these methods for multiplying the number of individuals for their gardens.

(1) **Underground Stems.** Many 'flowering' plants reproduce themselves by means of the rhizome, the tuber, the bulb and the corm. New buds are produced on these modified stems, which gradually grow up into new plants Common examples are afforded by ginger, potato, onion and *Gladiolus* (see FIGS. I/27-30).

(2) **Sub-aerial Stems.** The runner, the stolon, the offset and the [illegible] plants like Indian pennywort (FIG. [illegible] ice (*Pistia*) and *Chrysanthemum* for [illegible] I/31-4).

(3) **Adventitious Buds.** In sprout-leaf plant (*Bryophyllum pinnatum*; see FIG. I/15B) a series of adventitious (foliar) buds are produced

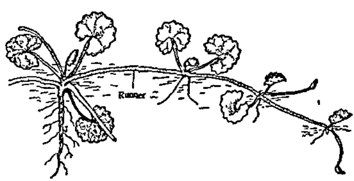


FIG. 55. Runner of Indian pennywort (*Centella*).

on the leaf-margin, each at the end of a vein; these buds grow up into new plants. In *Bryophyllum tubifolium* (FIG. 56) and *Kalanchoe*

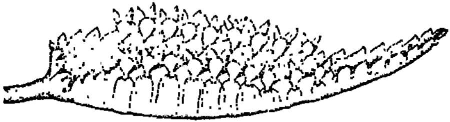


FIG. 56. A leaf of *Bryophyllum tubifolium* with adventitious buds.

(FIG. 57) there is profuse bud-formation from the leaf on the plant itself. The buds drop down from the leaf and grow up into new

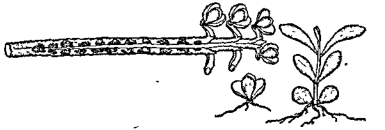


FIG. 57. A leaf of *Kalanchoe* sp. with adventitious buds.

independent plants. In elephant ear plant (*Begonia*; see FIG. I/15C) a few adventitious buds are produced on the surface of the leaf from the veins and also from the petiole. Similarly roots of some plants may produce adventitious (radical) buds for the same purpose, as in sweet potato (see FIG. I/9A), *Trichosanthes* (B. PATAL; H. PARWAL), wood-apple (*Aegle*), ipecac (see FIG. I/10B), etc.

(4) **Bulbils.** In *Globba bulbifera* (FIG. 58) and garlic (*Allium sativum*) some of the lower flowers of the inflorescence become modified into small multicellular bodies known as bulbils. They fall to the ground and grow up into new plants. Sometimes they are seen to grow to some extent on the plant itself. In American aloe or century plant (*Agave*; FIG. 60) and in some species of *Crassula* vegetative reproduction takes place by the formation of reproductive buds, also called bulbils, in place of many flowers of the inflorescence. Bulbils, big or small, are also produced in the leaf-axil of wild yam (*Dioscorea bulbifera*; FIG. 59) and *Lilium bulbiferum*. In wood-sorrel (*Oxalis*; FIG. 61) a large number

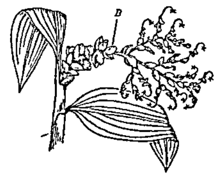


FIG. 58. *Globba bulbifera*. *B*, bulbil.

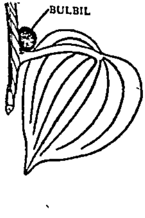


FIG. 59

FIG. 60

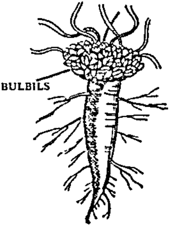


FIG. 61

FIG. 59. *Dioscorea bulbifera*. FIG. 60. Bulbil of American aloe (*Agave*). FIG. 61. Wood-sorrel (*Oxalis*).

of small buds (bulbils) may be seen on the top of the swollen, tuberous root. These buds being brittle at the base easily fall off and grow up into new plants. In pineapple (*Ananas*) the inflorescence generally ends in a reproductive bud; but in some varieties of pineapple (FIG. 62) the inflorescence becomes surrounded at the base by a whorl of such buds and also crowned by a few of them.

B. *ARTIFICIAL METHODS OF PROPAGATION*

In any of these methods a portion can be separated out by a special method from the body of the mother plant and grown independently. There are several such methods.

(1) Cuttings. (*a*) *Stem-cuttings.* Many plants like rose, sugarcane, tapioca, garden croton, China rose, drumstick (*Moringa*), *Duranta*, *Coleus* (see FIG. I/6), etc., may be easily grown from stem-cuttings. When cuttings from such plants are put into moist soil they strike roots at the base and develop adventitious buds which grow up. (*b*) *Root-cuttings.* Sometimes, as in lemon, citron, ipecac (see FIG. I/10B), tamarind, etc., root-cuttings put into moist soil sprout forming roots and shoots.

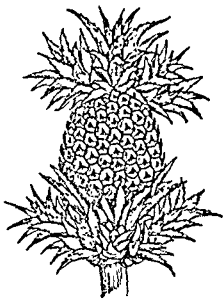


FIG. 62. Pineapple with a crown and a whorl of bulbils.

(2) Layering (FIG. 63). In this case a lower branch is bent down, a ring of bark to the length of 2.5-5 cm. removed and this portion pushed into the soft ground keeping the upper part free. The bend is covered with soil and a stone or brick placed on it. When it strikes roots, usually within 2-4 *months*, the branch is cut out from the mother plant and grown separately. Lemon, *Ixora*, rose, jasmines, grape-vine, etc., readily respond to this method.

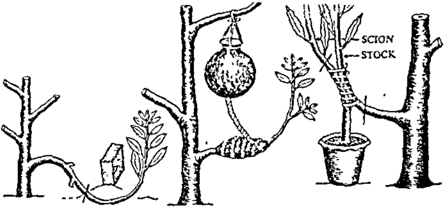


FIG. 63 FIG. 64 FIG. 65

Artificial Methods of Propagation. FIG. 63. Layering FIG. 64. Gootee. [illegible] or approach grafting.

[illegible]

early rains a healthy, somewhat woody [illegible]
of bark, 2.5 to 5 cm. in length, sliced off from it. A sufficiently thick

plaster of grafting clay[1] is applied all round the ringed portion which is then wrapped up with straw or rag and tied securely. It should be wetted with water every morning and afternoon. In drier climates an earthen pot with a hole at the bottom may be hung over the bandage in a convenient position, and the two connected by a long piece of cloth or soft cotton cord. As the pot is filled with water, the latter trickles down the cloth or cord and keeps the bandage constantly moist. Usually within 1-3 months the gootee is ready, as is indicated by its striking roots. It is then cut out below the bandage.

(4) **Grafting.** This consists of inserting a small branch of a plant into a rooted plant of the same or allied species in such a way as to bring about an organic union (fusion of tissues) between the two and finally make them grow as one. The branch that is inserted is known as the *scion* or *graft*, and the plant that is rooted to the soil as the *stock*. The scion grows retaining all its qualities, while the stock which may be of inferior quality but physically sturdy supports it by supplying water and food material. Grafting thus ensures the production of particular desired characters in the scion or graft, originally exhibited by the scion-mother. Grafts are prepared for the purpose of propagation of certain fruit and ornamental shrubs and trees. Some of the common methods are as follows:

bark is sliced off from each to ensure a closer contact and a quicker union between the two. When proper fusion has taken place, usually within 2-3 months, the stock is cut out above the joint and the scion below, thus leaving the scion standing on the stock. Some of the fruit trees like mango, litchi, guava, sapodilla plum, etc., readily respond to this method.

(*b*) **Bud Grafting** (FIG. 66). For this method a T-shaped incision is made in the bark of the stock, and a bud cut out clean from a selected plant is inserted

of *Hibiscus* on one, several varieties of cacti on one, and so on Luther Burbank of California was able to grow by bud grafting several varieties of prune and allied species on one stock.

(*c*) **Whip or Tongue Grafting** (FIG. 67). The stock, usually 1 to 1.5 cm. thick is cut down a few centimetres above the ground. Sloping cuts are made in it 5 or 7 cm. long, as shown in the figure. The scion of the same thickness is also cut in such a way as to fit exactly into the stock. It is then inserted into the stock and tied firmly. The wound is of course covered with grafting wax.[2] All buds are removed from the stock but not from the scion.

---

[1] **Grafting Clay.** Clay (2 parts), cowdung (1 part) and some finely cut hay mixed with water.

[2] **Grafting Wax.** A mixture of tallow (1 part), beeswax (1 part) and resin (4 parts), melted together and worked into a soft dough under water.

(*d*) Wedge Grafting (FIG. 68). The stock is cut 20 to 25 cm. above the ground and the wood of the stem incised with clean cuts in the form of a hollow V. The scion cut obliquely downward into a solid V so as to closely fit into the stock is inserted into the stock and tied firmly. Grafting wax is used to cover the wound.

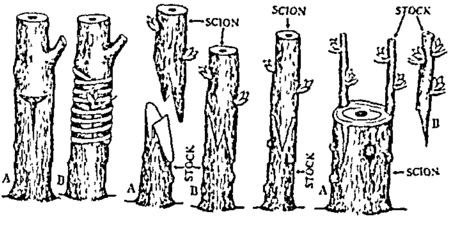


FIG. 66 FIG. 67 FIG. 68 FIG. 69

Artificial Methods of Propagation (*contd.*). FIG. 66. Bud grafting. FIG. 67. Whip or tongue grafting. FIG. 68. Wedge grafting. FIG. 69. Crown grafting.

(*e*) Crown Grafting (FIG. 69). An old tree may be rejuvenated by this method. The stem is cut across 20 to 25 cm. above the ground. The bark of the stock is cut through from the surface downward to a length of 12 to 15 cm. The bark is partially opened on either side. Prior to this a small branch cut out from another tree of the same species is incised at the base with a sloping cut and this is now inserted into the slit in the bark and tied firmly. The wound is of course covered with grafting wax.

Chimaera (or chimera). Chimaera refers to a fabulous monster with a *lion's head, goat's body and serpent's tail.* It means that chimaera is an organism which is *made up of two or more genetically distinct tissues. In plants the grafting* sometimes produces chimaeras, otherwise called graft hybrids. Here genetically distinct tissues (cells) of the two (stock and scion) become associated, evidently

mixtures in leaves or flowers or in both. Sometimes chimaeras may be produced on normal plants by bud mutations.

(2) Asexual Reproduction

Asexual reproduction thus takes place by two methods: fission and spore formation.

1. **By Fission.** In the simplest cases, as in many unicellular algae and fungi and in bacteria, the mother cell splits into two new cells. The new cells thus formed contain all the materials of the mother cell, and soon they grow to the size of the latter, becoming new independent plants. This method of reproduction by the division of the mother cell is called fission (see FIG. V/5C).

2. **By Spore Formation.** Spores are asexual reproductive units which can grow independently, i.e. without fusing with another unit, and are always unicellular and microscopic in size. They may be motile or non-motile.

(1) Ciliate motile spores, called **zoospores**, produced by many algae and fungi, swim about in water for some time with the help of their cilia, like minute aquatic animalcules, and then directly develop into new independent individuals. Zoospores are commonly formed in large numbers, as in *Ulothrix* (see FIG. V/17). In *Vaucheria* (FIG. 70), however, the whole mass of protoplasm escapes from the

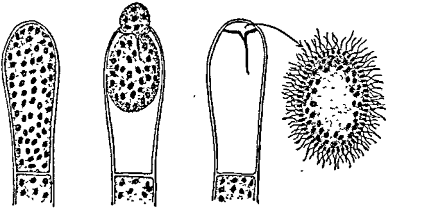


FIG. 70. Rejuvenescence in *Vaucheria*.

mother cell as a single large multiciliate and multinucleate zoospore. It swims in water for some time and then comes to rest. Almost immediately it germinates into a new *Vaucheria* filament. This is a case of **rejuvenescence**.

(2) Non-ciliate non-motile spores of various kinds are most common among terrestrial fungi. Such spores are light, dry and provided with a tough coat, and are well adapted for dispersal by wind; at the same time they are resistant to unfavourable atmospheric conditions.

(3) True spores are always borne by a sporophyte. Thus the sporogonium (sporophyte) of moss reproduces asexually by spores. Simi-

larly ferns, *Lycopodium* and *Equisetum* bear spores and reproduce asexually by them. It is further to be noted that these plants are *homosporous*, i.e. they bear only one kind of spores. In more advanced types of plants, e.g. *Selaginella* and 'flowering' plants (both gymnosperms and angiosperms), the spores are of two kinds: microspores and megaspores.

(3) Sexual Reproduction

This consists in the fusion of two sexual reproductive units, called gametes, which, like the spores, are also unicellular and microscopic. To reproduce sexually two gametes of opposite sexes fuse together to give rise to a zygote; the zygote develops into a new plant. Sexual reproduction in which the pairing gametes are similar is known as conjugation, and that in which the pairing gametes are dissimilar is known as fertilization. The zygote is called zygospore in the case of conjugation, and is called oospore in the case of fertilization.

(1) **Conjugation.** In lower algae and fungi the pairing gametes are essentially similar, i.e. not differentiated into male and female. The union of such similar gametes, called isogametes, (*isos*, equal), is known as conjugation, and the zygote thus formed is called the zygospore; the zygospore grows into a new plant.

(2) **Fertilization.** In all the higher forms of plant life, on the other hand, the pairing gametes are dissimilar, i.e. differentiated into male and female. The union of dissimilar gametes, called heterogametes (*heteros*, different), is known as fertilization; and the zygote thus formed is called the oospore; the oospore grows into a new plant.

Gametes are always borne by the gametophyte. Moss is a gametophyte; it directly bears the gametes. In Pteridophyta the gametes are borne by a small green body, called the prothallus; so the prothallus is the gametophyte. In the 'flowering' plants the gametophyte is an extremely reduced body.

(4) Special Modes of Reproduction

1. **Apomixis.** Apomixis is an irregular mode of reproduction resulting in the development of an embryo without the intervention of fertilization. It may be (*a*) parthenogenesis, (*b*) apogamy and (c) sporophytic budding. (*a*) **Parthenogenesis** is the development of zygote from the egg-cell without the act of fertilization, as seen in many lower plants, e.g. *Spirogyra*, *Chara*, *Mucor*, *Saprolegnia*, certain ferns and certain species of *Selaginella* and *Marsilea*. In some 'flowering' plants, as in *Thalictrum*, *Alchemilla*, certain species of *Compositae* and *Solanaceae* the embryo also may develop by parthenogenesis, i e. without fertilization. In them the embryo may develop from a haploid egg-cell or diploid egg-cell. In the former case

although germination is more or less normal, the plant becomes small and sterile. In the latter case the plant is normal in all respects. Sometimes the ovary develops normally into a fruit without fertilization. This type of fruit development is called **parthenocarpy.** Parthenocarpic fruits are almost always seedless. Examples are found in certain varieties of banana, pineapple, guava, grapes, apple, pear, papaw, etc. It is rather peculiar that sometimes fruit formation may be induced by artificial pollination by foreign pollen from another species or even genus, but without subsequent fertilization. Sometimes mere spraying with certain chemicals (growth-promoting substances) like naphthalene-acetic acid results in the setting of fruits without fertilization (induced parthenocarpy). (*b*) **Apogamy** is the development of an embryo from any cell of the gametophyte (prothallus) other than the egg-cell, evidently without the intervention of gametes. The embryo so formed grows into the sporophyte. It is of common occurrence in ferns. In 'flowering' plants it is sometimes seen that one or more embryos may be formed from the synergids, as in onion (*Allium*), lily (*Lilium*), aconite (*Aconitum*) and *Iris*, or from an antipodal cell, as in onion (*Allium*). The synergid or antipodal cell may be haploid or diploid. (*c*) **Sporophytic budding** may sometimes occur resulting in the development of an embryo. This means that an embryo may be formed from the diploid cells of the nucellus, as in orange, mango, prickly pear (*Opuntia*), etc., or even from those of the integument, as in onion (*Allium*). The embryo thus formed is pushed into the embryo-sac during the course of its development.

2. **Apospory** (*apo*, off or without). Apospory is the development of the gametophyte directly from vegetative cells of the sporophyte without the intervention of a spore. In ferns the prothallus may develop from certain vegetative cells of the leaf in place of spores, or it may develop from one or more cells of the sporangium other than a spore. Apospory has been found in *Pteris*, *Asplenium*, *Osmunda* and certain other ferns. The gametophyte that develops by this method is commonly diploid, and it may bear both antheridia and archegonia. Apospory is also sometimes seen in some mosses.

Polyembryony. The occurrence of more than one embryo in the seed is known as *polyembryony*. Many species of both dicotyledons and monocotyledons exhibit this phenomenon. Polyembryony is, however, particularly common among conifers (see FIG. VI/16H). These embryos may be formed in the seed in a variety of ways: (1) there may be more than one egg-cell in the embryo-sac or more than one embryo-sac in the ovule, and all the egg-cells may be fertilized; or (2) a number of embryos may develop simultaneously from different parts of the ovule. Thus they may be formed from the synergids and antipodal cells (vegetative apogamy), from the fertilized egg-

cell or unfertilized egg-cell (parthenogenesis), and from the tissue of the nucellus and the integument by sporophytic budding (apospory). Examples have been found in onion, groundnut, mango, lime, lemon and orange (but not in shaddock and citron). Polyembryony is commonly found in conifers where there are many archegonia in the ovule. All the archegonia may be fertilized resulting in the formation of as many embryos as there are archegonia; but ultimately one embryo reaches maturity, while others die off. In addition, one or four embryos may be formed in *Pinus* from the fertilized egg-cell.

PART IV *Ecology*

Chapter 1 PRELIMINARY CONSIDERATIONS

Ecology (*oikos*, house; *logos*, knowledge) deals with the relations between plants or a plant community, or animals or an animal community (as they exist in their habitats) and the various factors of their environment. It investigates the various structural and functional peculiarities that have appeared in response to the conditions prevailing in the locality (environment). Ecology, therefore, involves both morphology (external and internal) and physiology. It should also be noted that plants give food and shelter to animals; while the effects of animals and human communities on plants are also manifold. A study of ecology necessarily includes both animals and plants, and also the interactions between them.

Interdependence between Plants and Animals. (*a*) **Food.** Green plants manufacture food and store it in their body, while animals mostly depend on this stored food. (*b*) **Oxygen.** Green plants purify the atmosphere by absorbing carbon dioxide and giving out pure oxygen. (*c*) **Shelter.** Plants furnish shelter to a variety of animals, particularly birds and wild beasts and forest dwellers. (*d*) **Clothing.** Many plants furnish materials for clothing, while silk worms, MUGA worms and ENDI worms are reared on mulberry plant, SOM plant (*Machilus bombycina*) and castor plant respectively. (*e*) **Drugs.** Many plants have curative values in different illnesses and are extensively used as drugs. (*f*) **Pollination.** Many

(*j*) **Civilization.** Plants have materially contributed to the growth of civilization.

Environment. Environment includes all the factors that affect the form and growth not only of individual plants, but also of plant associations. Environmental factors may be climatic or edaphic. The climatic factor includes temperature, light, water (rainfall), humidity and wind, and the edaphic factor includes physical and chemical properties of the soil (including its water-contents). To these two, may be added the biological factor which includes bacteria and protozoa mainly in the soil, and also other living plants and animals including human beings.

1. **Climatic Factors.** These include all the conditions of the atmosphere such as temperature, light, water (rainfall), wind, etc., affecting primarily the shoot system of the plant.

(1) **Temperature.** A certain temperature is essential for all the vital functions of the plant and for its growth. Temperature has practically no effect on the plant so far as change of form or structure is concerned. Under certain conditions some organs of the plant are thermotropic; for instance, the opening and closing of flowers and of stomata, the drooping of leaves at night, etc., are caused by heat. In many cases temperature helps the dehiscence of fruits and thereby causes dissemination of seeds Plants normally prefer a temperature varying from 20°C to 40°C. Active tissues have much less ability than dry seeds and spores to withstand extremes of temperature. Most flowering plants are killed at a temperature below 0°C. and above 45°C., while seeds remain uninjured at a temperature far beyond these limits. Freezing temperature or frost kills plants, but at high altitudes where frosts frequently occur plants become unusually resistant. Temperature has an important bearing on plant geography. We find a considerable difference between the flora of tropical, sub-tropical, temperate, arctic and alpine regions.

(2) **Light.** Physiologically light is a very important factor. It is responsible for the formation of chlorophyll and for carbon-assimilation; it accelerates transpiration. Although strong light checks growth it has a tonic effect on plants. Light induces certain kinds of movements like photonasty and phototropism. Relative length of day and night has a marked effect on the development of flowers and maturation of fruits. Of all parts of the plant the leaves undergo by far the greatest modifications under the action of light. Plants growing in shady places are called **sciophytes**, and they usually have large leaves which are thin in texture and sparsely distributed on the stem; the stem is thin with long internodes; both the stem and the leaves are glabrous; palisade tissue is poorly developed; the leaf consists largely or entirely of spongy tissue; epidermis often contains chlorophyll and the cuticle is thin; stomata may be present on both sides. Common examples are *Begonia*, aroids, wood-sorrel, ferns, mosses and liverworts. Plants which can only grow well in the light are called **heliophytes**, and they, on the other hand, have small leaves which are thicker and crowded together on the stem; the stem is stouter with short internodes; the stem and sometimes the leaves are very hairy; palisade tissue is well developed; epidermis is provided with a thick cuticle, but no chlorophyll; stomata are present on the lower side, often sunken or occluded. Aqueous tissue is

[illegible]

fall has a marked effect on the geographical distribution of plants.

Units of Vegetation. Vegetation is not uniform in any country. Depending on climatic and edaphic factors the vegetation of an area, big or small, may be divided into a number of natural units whose composition is different and distinct. A large unit of natural vegetation in an area under identical climatic conditions is called a **plant formation**. Formations are controlled by their own climate, and may be of the following types: deciduous forest, evergreen forest, coniferous forest, arctic tundra, alpine tundra, grassland, etc. A formation is said to be a **climax** (or climax formation) when it is dominated by one or more species which are abundant in it; for example, in evergreen forest there may be certain dominant tall trees, in scrub vegetation certain dominant shrubs, and in grassland certain dominant grasses or sedges. A climax is the direct effect of the climate.

A major subdivision of a plant formation is called an **association** Within the formation there may be a number of associations depending on sub-climates and nature of soil. An association is similar in general outward appearance, ecological structure and floristic composition, e.g. marsh association or hydrophytic, halophytic or xerophytic association. A plant association may have one or more dominant species. Within the association there may be **communities** of plants closely associated, e g. *Acacia-Dalbergia* (KHAIR-SISSOO) along the banks of large streams, different species of *Quercus* or *Rhododendron* in the Himalayas. When a community invades a new area it is termed a **colony**.

Succession. The primitive vegetation of an area is never stable; it passes through a series of changes until finally a stable form or climax is reached. It may start initially in water or on barren rock or elsewhere.

(*a*) **Hydrosere.** The series of changes in the vegetation of a pond, lake, marsh or a stream are together known as hydrosere. The vegetation originally starts with some submerged plants rooted to the soil. e.g. *Ceratophyllum, Vallisneria, Hydrilla, Naias, Chara, Potamogeton*, etc. They increase in number and form a sort of underwater garden. As older plants and also animals die, a thin substratum is at first formed; this is further thickened by accumulation of soil particles as a result of erosion and transportation. Soon various floating plants, some rooted to the soil, e g. water lily, lotus, *Euryale* (B. & H. MAKHNA), *Limnanthemum*, water chestnut, etc., and some entirely floating, e.g. water lettuce, water hyacinth, duckweed, bladderwort, *Salvinia, Ceratopteris* (a water fern), etc., invade the area. Some of them increase very rapidly and cover the water surface.

Often they kill the submerged ones either by cutting off light or by competition. With the death of one set of plants the ground is prepared for the next set, i.e. succession continues. The pond in the meantime is being silted up. At this stage, still with sufficient water, plants like *Phragmites*, *Arundo*, *Typha*, *Scirpus*, etc, which are partly submerged, begin to invade the area and establish themselves. Besides, plants like *Sagittaria*, *Jussiaea*, *Alisma*, several sedges and rushes occupy the available space. They grow and eventually die, and further sedimentation takes place. The substratum rises and water-depth decreases. The next stage is the appearance of wet soil and then dry soil. By now hydrophytes disappear giving place to mesophytes. Species of shrubs and trees that can stand waterlogging during the rainy season only make their appearance. Further invasion takes place. Finally a permanent forest stage is reached. This is the climax. The type of forest is determined by the amount of annual rainfall. If succession takes place in saline areas the hydrosere is called *halosere*.

(*b*) Xerosere. This is another interesting feature of succession. The series of changes in the vegetation of bare rocky beds, rocky hill-slopes, sand beds and other areas with extreme scarcity of water are together known as xerosere. The first invasion on rocks under such an extreme condition is that of crustose lichens which can only grow for a short period during wet weather and then undergo desiccation. They gradually spread and disintegrate rock into soil to some extent at least. Soon foliose lichens make their appearance. In due course humus accumulates and the soil becomes receptive for the next series. Some forms of hardy mosses now invade the area. Soil is in the process of formation, humus accumulates, and water is retained. The next series is the appearance of hardy short-lived annuals followed by biennials and perennials. They help further disintegration of rock into soil, accumulation of humus and retention of soil water. As herbaceous plants multiply in number, the lichens and mosses become scarce. The stage is now set for invasion of hardy shrubs which in due course form the dominant vegetation. The depth of the soil further increases, and soon becomes suitable for tree-growth. Trees at this stage are, however, stunted in growth and xeromorphic in habit, and are sparsely distributed. If conditions are favourable xeromorphic plants soon become replaced by mesophytes. Trees increase in number and new types of herbs grow in their shade. The invading trees soon become dominant forming a climax. If succession takes place in sandy areas the xerosere is called *psammosere*.

Ecesis. The term ecesis refers to all the processes that govern the development of vegetation in a new locality. It includes, therefore, seed-germination, plant-growth and reproduction, and any one of these processes may stand in the way of complete ecesis. Competition with neighbours and also among the invading plants may also be a setback in this direction. It is evident that ecesis is next in import-

ance to migration of plants to a new locality because migration alone cannot give rise to a new vegetation without ecesis, i e. without proper and favourable conditions for ecesis a vegetation cannot establish itself in a new environment.

Chapter 2 ECOLOGICAL GROUPS

Although plants sometimes occur as isolated individuals, more commonly we find that they become adapted to the same environment and are associated together in groups. The groups may include different plant species, belonging to different families, and differing in shape, size, form and relationship, but they live under the same environmental conditions of the soil, moisture, heat and light. Some of the common groups are described below.

1. **Hydrophytes.** Hydrophytes are plants that grow in water or in very wet places. They may be submerged or partly submerged, floating or amphibious. Their structural adaptations are mainly due to the high water content and the deficient supply of oxygen. The various adaptations met with in hydrophytes are as follows.

Adaptations. The main features of aquatic plants are the reduction of protective tissue (epidermis here is meant for absorption, and not for protection), supporting tissue (lack of sclerenchyma), conducting tissue (minimum development of vascular tissue) and absorbing tissue (roots mainly act as anchors, and root-hairs are lacking), and the special development of air-chambers for aeration of internal tissues.

The root system in hydrophytes is feebly developed and root-hairs and root-cap are absent. In some floating plants such as bladderwort (*Utricularia*), hornwort (*Ceratophyllum*), etc., no roots are developed at all, and in submerged plants such as *Vallisneria*, *Hydrilla*, *Naias*, etc., water, dissolved mineral salts and gases are absorbed by their whole surface. In plants like water lettuce (*Pistia*), water hyacinth, duckweed (*Lemna*), etc., no root-cap develops, but an analogous structure called root-pocket is formed instead.

The stem is soft and more or less spongy, owing to the development of a large number of air-cavities in it and also in the leaf, filled with gases: these air-cavities on the one hand give buoyancy to the plant for floating and on the other serve to store up air (oxygen and carbon dioxide). The carbon dioxide that is given off in respiration is stored in these cavities for photosynthesis, and again the oxygen that is given off in photosynthesis during the daytime is similarly stored in them for respiration. There is a minimum development of the

mechanical and the vascular tissues. Xylem is reduced to only a few elements, while phloem is reduced to a few narrow sieve-tubes. The epidermis has no cuticle on it, but contains some chloroplasts. The stem and the leaf-stalk are in some cases provided with prickles and spines for defence against the attack of aquatic animals.

FIG. 1. Giant water lily (*Victoria regia*).

Aquatic plants may be fixed to the substratum or they may be floating freely. Leaves likewise may be submerged or floating. Submerged leaves are thin, and often become elongated owing to subdued light under water; they are generally ribbon-shaped, finely dissected or linear. Cuticle is absent and so usually are the stomata; the latter, if present, are functionless. Exchange of gases and absorption of water and mineral salts take place through the epidermis of the leaf. The mesophyll is thin and not differentiated

into palisade tissue and spongy tissue, and the epidermis contains chloroplasts to utilize the weak light under water. Floating leaves are well developed, and have a thick cuticle and a large number of stomata on the upper surface; no stomata or only *functionless ones* are present on the lower surface. Exchange of gases takes place through the upper surface, and absorption of water through the lower. Many air-cavities develop in them for the purpose of aeration and necessary buoyancy. Amphibious plants are subjected to alternate flooding and drying. They usually grow at the edge of a pool of water with lower leaves submerged and upper ones above water. Many such plants often show **heterophylly** (*heteros*, different; *phylla*, leaves), i.e. they bear different kinds of leaves on the same plant (see pp. 53-4).

Some Common Aquatic Plants. A. Submerged: *Vallisneria, Hydrilla, Naias, Ottelia, Potamogeton*, etc. **B. Floating:** *Wolffia, Hydrocharis*, bladderwort, hornwort, duckweed, water lettuce, water hyacinth, water chestnut, *Neptunia, Azolla, Salvinia, Ceratopteris*, etc. **C. Plants with floating leaves:** water lily (see FIG. VII/8), giant water lily (FIG. 1), *Euryale* (B & H. MAKHNA), *Limnanthemum*, etc. In lotus (*Nelumbium*) the leaves stand above the water. **D. Amphibious plants showing heterophylly:** water crowfoot (*Ranunculus aquatilis*), water plantain (*Alisma*), arrowhead (*Sagittaria*), *Limnophylla heterophylla, Cardenthera triflora*, etc.

2. **Hygrophytes.** These are plants that grow in constantly moist situations. They occur in moist shady places, in forests, or in the moist soil near waterlogged localities. The root system and the vascular system in hygrophytes are poorly developed. Plants are stunted in growth, their parts generally soft and spongy, and the stem usually an underground rhizome. There is a feeble development of mechanical tissues. Leaves on the whole are well developed, fully expanded, and with numerous stomata. They are smooth, shining and with a thin cuticle. The situation in which these plants grow being moist, transpiration is not active, but to get rid of the excess water, leaves are provided with hydathodes (see FIG. II/39) through which exudation of water takes place in liquid form. Common hygrophilous plants are aroids, ferns, begonias, some grasses, etc.

3. **Mesophytes.** These are plants that grow under average conditions of temperature and moisture; the soil in which they grow is neither saline nor is it waterlogged, and the temperature of the air is neither too high nor too low. Mesophytes are, therefore, intermediate between hydrophytes and xerophytes.

Adaptations. The root system is well developed with the tap root and its branches in dicotyledons, and a cluster of fibrous roots in monocotyledons; root-hairs are luxuriantly produced for the ab-

phytes, e.g. *Cereus triangularis* (see FIG. VII/28A), *Scindapsus* (B. GAJPIPAL), etc.; conversely some plants are epiphytic at first and later terrestrial being rooted to the soil, e.g. banyan, peepul, etc.

Examples. Among the angiosperms orchids predominate as epiphytes, e.g. *Vanda* (see FIG. I/13), *Dendrobium* (see FIG. VII/68), *Cymbidium*, *Eria*, etc., while certain plants of *Araceae*, e.g. *Scindapsus officinalis*, *Pothos scandens*, *Bromeliaceae*, e.g. *Tillandsia usneoides* —a peculiar American plant hanging from branches and looking like *Usnea* (a lichen; see FIG. V/86), *Asclepiadaceae*, e.g. *Dischidia rafflesiana* (see FIG. I/67) and *D. nummularia*, *Cactaceae*, e.g. *Cereus triangularis*—a large climbing epiphyte with triangular stem often reaching tree-tops, etc. Among Pteridophyta several ferns are epiphytes, e.g., bird's nest fern (*Asplenium nidus*), *Drynaria quercifolia* with dimorphic leaves, many species of *Polypodium*, e.g. *P. fissum*—all growing in tufts on tree-trunks, and *Cyclophorus adnascens*—creeping, branching and almost covering the whole tree, etc.; a few species of *Lycopodium*, e.g. *L. phlegmaria* (see FIG. V/122) and *L. squarrosum*, are also somewhat common epiphytes. Among Bryophyta several forms of mosses often cover tree-trunks as cushions; *Porella* (see FIG. V/103), one of the Jungermanniales, is also fairly common. Among algae mention may be made of *Protococcus* and *Trentepohlia* growing on barks of trees, the latter on leaves also.

5. **Xerophytes.** These are plants that grow in deserts or in very dry places; they can withstand a prolonged period of drought uninjured; for this purpose they have certain peculiar adaptations. Xerophytes are really drought-resistant plants. It is not that they thrive under desert conditions. The property of drought-resistance is not attributed to the anatomical features of such plants but to the capacity of the protoplasm to endure a high degree of desiccation with practically no injury. Dominant factors in a desert or a very dry region are: scarcity of moisture in the soil and the extreme atmospheric conditions such as intense light, high temperature, strong wind and aridity of the air. These being so, the xerophytic plants have to guard against excessive evaporation of water; this they do by reducing evaporating surfaces. They have also to adopt special mechanisms for absorbing moisture from the soil and for retaining it in their body. Xerophytic characters are also found in plants growing in cold regions such as temperate and sub-arctic zones and high altitude, rocky beds, sandy regions, dry places with scanty rainfall, and in salt marshes.

Adaptations. Plants produce a long tap root which goes deep into the subsoil in search of moisture; many of the desert plants which live for a short period produce a superficial root system to absorb moisture from the surface-soil after a passing shower of rain. To retain the water absorbed by the roots, the leaves and stems of some

plants become very thick and fleshy, as in Indian aloe (*Aloe*) and American aloe or century plant (*Agave*); sometimes, roots also become fleshy, as in *Asparagus*. Aqueous tissue develops in them for storing up water; this is further facilitated by the abundance of mucilage contained in them. Multiple epidermis sometimes develops in the leaves for the same purpose, as in oleander (*Nerium*). Modification of the stem into phylloclade for storing water and food and at the same time performing functions of leaves is characteristic of many desert plants, e.g. most cacti and some species of *Euphorbia*.

Leaves and stems are provided with thick cuticle; epidermal cells often become strongly cutinized to prevent loss of water by transpiration. In many cases the stem becomes reduced in size and provided with thorns, as in *Euphorbia spinosa*. Leaves are also reduced in size minimizing their evaporating surfaces. Thus these may be divided into small segments, as in *Acacia*, or modified into spines, as in many cacti and spurges (*Euphorbia*), or sometimes reduced to small scales only, as in *Tamarix* and *Asparagus*. In some plants, as in *Gnaphalium* and *Aerua*, there is a dense coating of hairs. Stomata are fewer in number—usually 10-15 per sq. mm., and these remain sunken in grooves and occluded. There is a strong development of sclerenchyma in most of the xerophytes. Modification of the leaf into phyllode, turning its edge in the vertical direction in strong sunlight to minimize transpiration, is characteristic of Australian *Acacia* (see FIG. I/65). Under conditions of extreme dryness leaves of most xerophytic grasses and also of many other plants roll up, considerably reducing their evaporating surfaces. In such cases stomata also become shut up.

Many of the xerophytic herbs lie prostrate on the ground, completing their life-history within a short time, e.g. *Solanum xanthocarpum, Tribulus terrestris, Trianthema monogynum* and *Suaeda fruticosa*; some are perennial in habit. Many xerophytes are elaborately armed with prickles and spines.

Two very peculiar cases showing special xerophytic adaptations may be mentioned here. These are certain species of *Selaginella* and *Anastatica* When the dry season prevails in the desert, these plants curl up into a sort of ball, and are driven about by the wind. They are fixed only when they reach wet soil or the rains begin.

Some Common Xerophytic Plants. Many spurges (*Euphorbia*), e g. *Euphorbia royleana, E. neriifolia*, etc., many cacti, e.g. prickly pear (*Opuntia*), *Cereus, Pereskia*, etc., dagger plant (*Yucca*; see FIG. I/78), Indian aloe (*Aloe*), American aloe or century plant (*Agave*), *Capparis aphylla, Tamarix*, prickly poppy (*Argemone*), jew's slipper (*Pedilanthus*), globe thistle (*Echinops*), safflower (*Carthamus*), amaranth (*Amarantus*), wild plum (*Zizyphus nummularia*), purslane (*Portu-

laca), Indian spinach (*Basella*), saltwort (*Salsola*), sea-blite (*Suaeda*), *Asparagus*, gum tree (*Acacia*), camel thorn (*Alhagi*), *Solanum xanthocarpum* (B. KANTIKARI; H. KATELI), *Tribulus terrestris* (B. GOKHRI-KANTA; H. GOKHRU), *Gnaphalium*, *Aerua*, etc. Common xerophytic grasses are *Stipa*, *Sporobolus*, *Saccharum spontaneum* (B. KASH; H. KANS), *S. munja* (B. SAR; H. MUNJA), *Aristida*, etc.

6. **Halophytes.** These are plants that grow in saline soil or water with a preponderance of salts in it. Hence halophytes show some special characters (or adaptations).

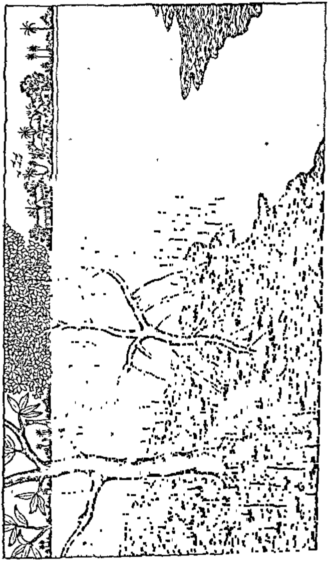


FIG. 2. Mangrove plants showing (a) pneumatophores for respiration, (b) stilt roots for support, and (c) viviparous germination for survival.

Xerophytic Adaptations. The majority of halophytes show xero-

phytic adaptations.[1] Most of them have succulent leaves; some have a succulent stem also. Leaves may be modified into, or provided with, spines. Examples of halophytes are sea-blite (*Suaeda maritima*), *Salicornia brachiata*, saltwort (*Salsola*), *Acanthus ilicifolius*, goosefoot (*Chenopodium*), *Basella* and some species of *Amarantaceae*.

Special Adaptations. Halophytes growing on muddy swamps of tropical estuaries and sea-coasts inundated by tides almost daily form a special vegetation known as mangrove. Mangrove vegetation is most extensively represented in the Sundarbans (West Bengal). Mangrove plants show some special adaptations. (1) They produce a large number of stilt roots (FIG. 2) from the main stem and the branches. (2) In several cases, in addition to the stilt roots special roots, called **respiratory roots** or **pneumatophores** (FIGS. 2-3),

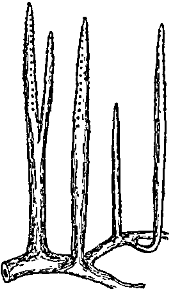


FIG. 3

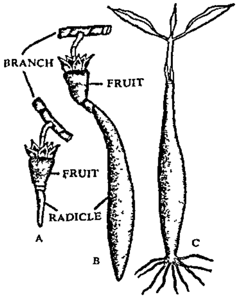


FIG. 4

FIG. 3. Pneumatophores growing vertically upwards from an underground root. FIG. 4. Viviparous germination.

are also produced in large numbers. They develop from underground roots, and projecting beyond the water level they look like so many conical spikes distributed all round the trunk of the tree. In some places they grow so thickly that passage through them by boat is difficult. They are provided with numerous pores or respiratory spaces in the upper part, through which exchange of gases for respiration takes place. (3) Mangrove species also show vivipary (FIG. 4), i.e. the seed germinates inside the fruit while it is still on the parent

[1] The saline water or soil was believed to be 'physiologically dry' and hence the xerophytic adaptations. It is now, however, definitely known that these adaptations are the result of physiological reaction of excess of salts on plants.

tree and is nourished by it. Germination is almost immediate without any period of rest. The radicle elongates to a certain length and swells at the lower part. Finally the seedling separates from the parent tree and falls vertically down. The radicle presses into the soft mud, keeping the plumule and cotyledons clear above the saline water. Lateral roots are quickly formed for proper anchorage. The advantage is that the fruit cannot be swept away by tidal waves. Typical mangrove plants are *Rhizophora*, *Ceriops* (B. GORAN), *Kandelia* (B. GORIA), *Bruguiera* (B. KANKRA), *Sonneratia* (B. KEORA), *Heritiera* (B. SUNDRI), *Excoecaria* (B. GEO), *Avicennia* (B. BAEN or BINA), etc. (See also p. 363.)

7. **Marsh Vegetation.** A marsh is a tract of low, wet land. During the greater part of the year it remains covered with water; for a shorter period it is dry. There is stagnant mud in a marsh with abundance of mineral salts. The water is alkaline or even neutral but not acid. The peculiarity of marsh vegetation is that the submerged parts show hydrophytic adaptations; while the aerial parts have the peculiarities of land plants. From the margin to the mid-marsh the vegetation shows often three zones with, of course, a certain amount of overlapping. The first or the outermost zone, lying nearest the dry land, is composed of plants whose roots or rhizomes only are in waterlogged areas. This zone exhibits to some extent the characteristics of hygrophytes. Leaves are usually well developed with numerous stomata but with thin cuticle, and the stem usually spongy in nature. There is dominance of low herbs in this zone, the common plants being water dropwort (*Oenanthe*), marsh pennywort (*Hydrocotyle*), various sedges (*Scirpus*, *Carex*, etc.), rush (*Juncus*), horsetail (*Equisetum*), etc.

The second or the intermediate zone lies between the first zone and the mid-marsh. Here the roots or rhizomes are in the wet soil under water, parts of the stem are in water, and the leaves and flowers are either floating or raised above water. This zone is characterized by tall herbs of upright growth. Typical plants of this zone are reed (*Phragmites*), *Arundo donax*, bulrush (*Typha*), etc. This zone is often called reed-swamp association. Low herbs or floating plants associated with them are water plantain (*Alisma*), water crowfoot (*Ranunculus*), water lilies (*Nymphaea*), lotus (*Nelumbium*), duckweed (*Lemna*), water lettuce (*Pistia*), arrowhead (*Sagittaria*), hornwort (*Ceratophyllum*), *Hydrilla*, *Vallisneria*, *Utricularia* as well as some floating grasses such as *Hygrorhiza*, *Vossia*, *Panicum proliferum*, etc., and some sedges such as *Scirpus*, *Cyperus*, etc.

The third or the innermost zone is submerged, and the vegetation typically hydrophytic. Common plants of this zone are *Potamogeton*, *Vallisneria*, *Hydrilla*, *Ceratophyllum*, etc. Besides, many of the aquatic plants of the second zone extend into this zone.

Chapter 3 PHYTOGEOGRAPHICAL REGIONS OF INDIA

The division of India into certain phytogeographical regions was first proposed by Clarke in 1898. It was revised by Hooker in 1907. On more information being available it was further modified by Chatterjee[1] in 1939. The main factor in the distribution of species is the amount of annual rainfall in a particular region; within the region the type of soil is another important factor. In the mountainous regions such as the Himalayas the altitude is the dominant factor, coupled with rainfall, determining zonal vegetation. Where rainfall is heavy, over 2,000 mm., sometimes very heavy, as in Assam, North Bengal and Malabar, luxuriant vegetation with evergreen forests and diversity of species is the rule; where rainfall is low (usually 1,000-1,500 mm.), as in Deccan, Central India and parts of Punjab, sparse vegetation with deciduous forests and uniformity of species is the rule; and where rainfall is very low (500-760 mm.), sometimes much less, as in South Punjab, Rajputana and Sind (Pakistan) the vegetation is thin, sparse and xerophilous, with thorny scrubs predominating. Based on the above factors India may be divided into the following phytogeographical regions.

1. Deccan consisting of Deccan Plateau (Madras, Andhra and major part of Mysore), a hilly tract of land, with an annual rainfall of 840-1,000 mm., and Central India (Madhya Pradesh, Orissa and part of Gujarat) with an annual rainfall of 840-1,400 mm., shows the following types of vegetation: (*a*) dry deciduous forests predominating, with teak (*Tectona*), *Acacia*, nux-vomica (*Strychnos*), *Lagerstroemia*, Indian rosewood (*Dalbergia*), *Dillenia*, *Cassia*, *Terminalia*, sandalwood (*Santalum*) in Mysore, red sandalwood (*Pterocarpus*), *Butea*, *Dillenia*, *Odina*, *Grewia*, *Buchanania*, etc.; (*b*) SAL (*Shorea*) forests in Central India extending to Orissa; (*c*) thorny [illegible] area. In the above region black soil covering a wide area is extensively used for the cultivation of cotton.

2. Malabar consisting of the Western Ghats and extending from Gujarat to Travancore with an annual rainfall of over 2,500 mm. shows luxuriant vegetation of the following types: (*a*) tropical evergreen forests with luxuriant growth of trees, mainly *Hevea* and *Ficus*

[1] *Studies on the Endemic Flora of India and Burma* by D. Chatterjee, 1939.

elastica (both rubber-yielding), *Dipterocarpus*, *Artocarpus*, sandalwood (*Santalum*), nutmeg (*Myristica*), ebony (*Dyospyros*), toon (*Cedrela*), Alexandrian laurel (*Calophyllum*), coconut-palm (*Cocos*), *Mimusops*, *Hopea*, *Sterculia*, etc ; there is also a rich growth of shrubs, climbers and epiphytes; (*b*) deciduous forests occurring in strips with an annual rainfall 1,500-2,000 mm.; the vegetation is sparse and trees mostly deciduous; common trees are mountain ebony (*Bauhinia*), teak (*Tectona*), Indian redwood (*Dalbergia*), *Adina*, *Lagerstroemia*, *Terminalia*, *Grewia*, bamboo (*Bambusa*), etc.; (*c*) temperate evergreen forests at higher elevations with a rich vegetation of evergreen trees, mainly *Michelia*, *Eugenia*, *Ternstroemia*, etc.

3. **Indus Plain.** The average rainfall is very low—Punjab 630-760 mm., Rajputana 250-500 mm., and Sind (Pakistan) 200 mm.; north-eastern Punjab, however, is somewhat wet. A large tract of land in Rajputana is covered with THAR or Great Indian desert. The vegetation in its outskirts is typically xerophytic. Mean humidity of the plain is 50-52 or less, and is responsible for very hot summers and very cold winters. **Soils.** Tracts of land impregnated with salts, called KALLAR, are widely distributed. In Sind Sagar Doab, in southern Punjab and in the districts north of Rajputana the soil is very sandy and highly unstable, often forming dunes. Along the banks of larger rivers the soil, though sandy, has abundance of moisture. Black saline soil, called RAPAR, is devoid of any vegetation.

Vegetation. (*a*) **Desert Thorn Forest.** *Prosopis spicigera*, *Salvadora oleoides*, *Capparis aphylla*, etc , are dominant. Associated with them are commonly found *Tamarix articulata*, *Acacia leucoploea*, *A. arabica*, *A modesta*, *Albizzia lebbek*, *Morus alba*, *Zizyphus jujuba*, etc. *Sporobolus arabicus*, an Arabian grass, associated with saltwort (*Salsola foetida*), sea-blite (*Suaeda fruticosa*), *Chenopodium*, etc , is seen to remain confined to the saline soil. Plants like *Acacia arabica*, *Tamarix articulata*, *Butea frondosa*, etc., also stand saline conditions well. Plants forming undergrowth are *Calotropis procera*, *Kochia indica*, *Chenopodium album*, *Zizyphus nummularia*, *Asparagus gracilis*, *Ephedra foliata*, etc. (*b*) **Dune Scrub.** In Sind, southern Punjab and Rajputana the vegetation is open, irregular and xerophytic. Stunted trees and bushes, thorny in character, form the only type of vegetation. Dominant species are *Leptadenia spartium*, *Euphorbia royleana*, *Acacia jacquemontia* (the only tree form), *Crotalaria burhia*, *Sericostoma pauci-euphratica*), etc , richly associated with *Tamarix dioica*, *Acacia farnesiana*, *A. arabica*, *Sachharum spontaneum*, *S. munja*, etc.

4. **Gangetic Plain** with (*a*) an upper dry region extending from Punjab with an average annual rainfall of about 500 mm. to Allahabad with a rainfall of about 1,000 mm., (*b*) a lower humid region extending from Allahabad to West Bengal with a rainfall gradually

increasing to 1,900-2,500 mm., and (*c*) gangetic delta including the vast expanse of the Sundarbans.

The Sundarbans. The lower gangetic plain nearest to the sea—a large tract of land, called the Sundarbans, with a network of water-channels, sea-creeks and swampy islands—is densely covered with extensive tidal swamp-forests of the Malayan type. This tract of land spontaneously separates itself from the upper alluvial plain. The vegetation is dense and compact, and consists of species distinct from the rest of the gangetic plain except its northern boundary with mixed types. The rivers are subject to tidal influence and are, therefore, saline. The numerous islets are mostly covered with savannahs composed of reed (*Phragmites karka*) associated with other tall grasses and tall sedges, and often dotted with trees. Throughout much of the Sundarbans the vegetation is of the mangrove type which is more pronounced towards the sea-face. The dominant feature of the mangrove is *Rhizophoraceae* consisting of the following typical mangrove trees: *Rhizophora mucronata* (BARRA-KHAMO), *R. conjugata* (KHAMO), *Ceriops roxburghiana* (GORAN), *Kandelia rheedei* (GORIA), *Bruguiera gymnorhiza* (KANKRA), etc. Associated with them are other mangrove species like *Heritiera minor* (SUNDRI—*Sterculiaceae*) which is very widespread in the area, *Excoecaria agallocha* (GEO—*Euphorbiaceae*) which is also plentiful, *Aegiceros majus* (KULSI—*Myrsinaceae*), *Sonneratia apetala* (KEORA—*Lythraceae*), *Avicennia officinalis* (BAEN or BINA—*Verbenaceae*) which is the largest tree in the Sundarbans, etc. Palms like *Nipa fruticans* (GOLPATA) and *Phoenix paludosa* (HITAL) are characteristic mangrove species. Coconut-palm (*Cocos nucifera*) and cane (*Calamus tenuis*) grow extensively, often planted. Along the edges of streams, canals, ponds and swamps bulrush or cat-tail (*Typha angustata* and *T. elephantina*), *Alpinia allughas*, screw-pine (*Pandanus fascicularis*), etc., are very common *Panicum repens* and *Ipomoea pes-caprae* are two important sand- and mud-binding species. *Acanthus ilicifolius* (HARGOZA), *Hygrophila spinosa* (KULEKHARA), salt-blite (*Suaeda maritima*), *Salicornia brachiata*, *Arthrocnemum indicum*, *Tamarix gallica* (BAN-JHAU), *Allophylus cobbe*, *Crotalaria retusa*, *Derris sinuata*, etc., are some of the other common plants of the area. 13 species of *Orchidaceae*, some epiphytic ferns, *Lycopodium phlegmaria* (see FIG. V/122), *Aldrovanda vesiculosa* (see FIG. III/29), *Psilotum* (in the eastern Sundarbans), etc., have been recorded from this area. Apart from botanical interest the flora of the Sundarbans is economically very important, being the source of timber and firewood Many medicinal plants also grow in in this area.

5. **Assam.** The climatic factors of Assam are high humidity (80-90), frequent rainfall and moderate temperature without extremes of heat or cold (generally 29°-19°C. in the plains); and edaphic factor—high fertility of the soil. The average rainfall is heavy but varies—in lower Assam the average is 2,000 mm., in upper Assam 3,200 mm., in Cachar and Mizo (Lushai) Hills 2,900 mm. or more, in Garo Hills 2,700 mm., in Khasi and Jaintia Hills 5,800 mm. (in Shillong, however, 2,000 mm.), with the heaviest in Cherrapunji 12,700 mm. or more and its neighbourhood (Moushinram) 15,200 mm. or more. The Brahmaputra flows through the whole length of Assam valley with alluvial deposits on either side. Assam is a country of rivers, hills and plains, extraordinarily rich in vegetation; a region

of the Khasi Hills above the pine zone (2,000 metres) is considered the richest, not only in India but perhaps in the whole world (see *Flora of Assam*, vol. I). The flora of Assam may be divided into the following types.

(*a*) **Evergreen Forests.** With abundant rainfall this type of forests extends in a more or less continuous belt from the north-east corner of NEFA to the Darrang district along the foothills of the Himalayas; such forests also occur in the Nowgong district, Cachar district and greater part of the Khasi Hills; elsewhere they are found to occur in isolated patches. These forests are composed of a very large number of species, and present a 3-storeyed appearance. The top storey consists of some isolated tall, evergreen or deciduous trees (some 46 metres high) towering above others, of which the following are common—*Dipterocarpus macrocarpus* (HOLLONG), *Artocarpus chaplasha* (CHAM), *Tetrameles nudiflora*, *Terminalia myriocarpa* (HOLLOK), etc. The middle storey consists of several medium-sized trees (up to about 23 metres) such as *Calophyllum*, *Mesua* (NAHOR), *Amoora* (AMARI), *Cinnamomum* (GONSEROI), *Phoebe* (BONSUM), *Machilus* (SOM), *Duabanga* (KHOKAN), *Ficus elastica* and other species, *Michelia*, *Magnolia*, etc The lowest storey is made up of several shrubs. Climbers and lianes are very common, as also epiphytes (many orchids, some ferns and aroids). In the Khasi Hills pine forests are evergreen but without undergrowths and climbers. Here pine is associated with several species of oak (*Quercus*), chestnut (*Castanopsis*), birch (*Betula*), etc., and in some places with yew (*Taxus*), *Cephalotaxus*, *Araucaria*, spruce (*Picea*), silver fir (*Abies*), deodar or cedar (*Cedrus*), *Tsuga*, *Cryptomeria*, cypress (*Cupressus*), juniper (*Juniperus*), etc. At high elevations in NEFA, particularly in Aka and Dafla Hills, the following conifers occur—*Podocarpus*, *Taxus*, *Abies*, *Pinus longifolia*, *P. excelsa*, *Tsuga* and *Cupressus*.

(*b*) **Deciduous Forests.** These forests occur mainly in the lower Assam Valley, Garo Hills and North Cachar Hills (particularly in the angle formed by the Mikir Hills and the Naga Hills), often mixed with some evergreen species. These tracts except the North Cachar Hills are mainly composed of *Shorea robusta* (SAL) forests and scrub forests, commonly associated with or surrounded by *Careya arborea* (KUMBHI), *Lagerstroemia* (AJAR), *Schima wallichii* (evergreen), *Dillenia pentagyna* (AKSHI), *Kydia calycina* (KOTRA), *Terminalia belerica* and *T. chebula*, *Cassia fistula* (SONARU), *Albizzia* (KOROI & MOZ), *Gmelina* (GUMHAR), *Stereospermum* (PAROLI), *Alstonia*, walnut (*Juglans*), *Engelhardtia* (LEWA), *Dalbergia*, *Bombax*, *Sterculia* (ODAL), etc. *Shorea assamica* (MAKAI), often over 30 metres in height, forms pure forests in Lakhimpur. In the North Cachar Hills and the dry regions of Cachar where SAL is absent the forests are of mixed types and consist of *Dipterocarpus turbinatus* (GARJAN), *Bombax*, *Adina*, *Stephegyne*, several species of *Ficus*, *Cassia nodosa*, several grasses and bamboos (*Bambusa* and *Melocanna*). Further, *Coffea bengalensis* with white flowers, *Strobilanthes* with blue flowers, *Mussaenda* with white or yellow, leaf-like (modified) sepal, *Holmskioldia* with scarlet-red flowers, etc., adorn the deciduous forests as undershrubs and shrubs Storeys, so characteristic of evergreen forests, are absent in deciduous forests.

(*c*) **Swamp Forests.** Cachar abounds in swamps; small swamps are not uncommon in Assam Valley. Various aquatic and semi-aquatic grasses, e g *Panicum* (many species), *Phragmites*, *Arundo*, *Erianthus*, *Vossia*, *Hygrorhiza*, etc., and sedges, e.g. species of *Scirpus* and *Cyperus*, etc., occur. Besides, *Ceratopteris* (an

aquatic fern), *Azolla*, *Salvinia*, *Marsilea*, etc., and among 'flowering' plants *Euryale*, *Alpinia*, water lilies (*Nymphaea*), lotus (*Nelumbium*), etc., are quite common. At the edges of such swamps are commonly found *Barringtonia* (HIZAL), *Cephalanthus* (PANI-KADAM), *Clinogyne* (SITAL-PATI), *Ficus heterophylla*, *Dracaena spicata*, etc.

(*d*) Grasslands. These are widespread in low-lying areas, riparian tracts, and dry lands with low rainfall. In the wet tracts characteristic genera are *Phragmites*, *Arundo*, *Erianthus*, *Saccharum*, etc. They often cover extensive areas along the banks of large rivers, and some of them often grow to a height of 6 metres. In the dry lands the grasses are low and hardy, and are commonly *Imperata*, *Andropogon*, *Erianthus*, *Panicum*, *Apluda*, *Saccharum*, *Isachne*, etc.

(*e*) *Acacia-Dalbergia* (KHAIR-SISSOO) Forests. These forests extend along large streams at the foot-hills of the Bhutan Range from Goalpara district to Darrang district. *Acacia catechu* (KHAIR) and *Dalbergia sissoo* (SISSOO) are the two important species occurring in abundance in such forests. They occur mixed up with *Duabanga* (KHOKAN), *Bombax* (SIMUL), *Trewia* (PITULI), *Barringtonia* (HIJAL), etc., which are ubiquitous.

Interesting Aspects of the Flora of Assam. Some of the many interesting plants occurring in Assam deserve mention. Their morphological and physiological features and their economic importance have been described in the text. A general survey is given here. Many of them are rare found growing in Assam only. Insectivorous plants—pitcher plant (*Nepenthes khasiana*) in Garo Hills and Khasi Hills, *Drosera burmanni* in Jorhat and Khasi and Garo Hills, *Drosera peltata* and *Pinguicula alpina* on Shillong Peak, land *Utricularia* on hill-sides in Shillong. Saprophytes—Indian pipe (*Monotropa uniflora*) and *Burmannia* (4 sp.) in Khasi Hills. Root-parasites—*Balanophora dioica* in Khasi Hills, and *Sapria himalayana* (akin to *Rafflesia*) in Aka, Dafla and Naga Hills. Orchids abound (estimated to be near about 400 species) and so do many beautiful ferns and some tree ferns. Other interesting plants—*Coptis teeta* (a medicinal plant) in Mishmi Hills; *Aquilaria agallocha* (AGARU) in Sibsagar; *Mussaenda* (9 sp.), lady's umbrella (*Holmskioldia*) and *Cycas pectinata* adorning low hills; *Rhododendron* (several sp) at high elevations; *Gnetum gnemon* (a shrub) in Sibsagar and some other districts, *Gnetum montana* (a climber) throughout the State;

tensive uses; bamboos (*Bambusa*, *Melocanna*, *Arundinaria*, *Dendrocalamus*, etc.) about 20 sp., and canes (*Calamus*, *Zalacca*, *Daemonorops*, etc.) about 14 sp.

much less rainfall; and (*c*) the Western Himalayas extending from the Kumaon Hills to Peshwar (Pakistan), with rainfall gradually decreasing from 1,100 mm. to about 500 mm.

The single dominant factor responsible for zonal vegetation of the Himalayas is the altitude (and, therefore, decreasing temperature), each zone having its characteristic flora with of course some or even

considerable amount of overlapping, i.e. without any line of demarcation between one zone and the next. Three broad zones may, however, be more or less distinctly recognized, viz. (*a*) tropical zone with warm to mild climate; (*b*) temperate zone with mild to cold climate; and (*c*) alpine zone with intensely cold climate, merging into the snow-line. Within the zone rainfall and topography are the next important factors, the western wing of the Himalayas being drier and the eastern wing wetter. Within each zone often two sub-zones are distinguishable.

(*a*) **Tropical Zone** (500-1,600 metres). This forms the submontane belt of the Himalayas, called Terai, and is covered by dense forests. Depending on rainfall two types of forests develop in this zone—evergreen with abundant rainfall (over 2,500 mm) in the eastern wing, and deciduous with scanty rainfall (1,100 mm. or much less) in the western wing. On the whole SAL (*Shorea robusta*) forests are dominant in this zone (uninfluenced by rains). Other common trees of this zone are *Lagerstroemia*, *Bauhinia*, *Bombax*, *Cassia fistula*, flame of the forest (*Butea*) and many timber trees (see part IX-J) Several species of *Melastoma*, *Osbeckia*, *Strobilanthes*, *Coffea bengalensis*, many grasses, ferns, etc., form the undergrowth. Climbers and lianes are abundant, and so also clumps of bamboos and wild bananas. Tree trunks are densely covered with mosses and lichens. Above 1,000 metres pines gradually become the dominant feature of vegetation (see below).

(*b*) **Temperate Zone** (1,600-3,500 metres). Coniferae and Cupuliferae (*Betulaceae* and *Fagaceae*) are dominant in this zone. In the lower temperate sub-zone pine forests predominate (*Pinus khasya* in the east, and *P. longifolia* in the west), associated with *Podocarpus* here and there. In the higher temperate sub-zone deodar (*Cedrus deodara*) predominates. Associated with pines and other conifers (see below) occur oak (*Quercus*), beech (*Fagus*), *Castanopsis*, birch (*Betula*), alder (Alnus), poplar (*Populus*), willow (*Salix*), maple (*Acer*), elm (*Ulmus*) walnut (*Juglans*), *Schima khasiana*, etc., most of which ascend upwards to 3,500 metres or even higher *Bucklandia*, a handsome tree, is spotted here and there. *Rhododendron* (125 sp. in the Himalayas) deserves special mention. At lower elevations of this zone the species of this (e g. *R. arboreum*) are trees or large shrubs, higher up the species are mostly shrubby; still higher up in the cold temperate sub-zone the species are further stunted in growth. The temperate zone as a whole is rich in vegetation and abounds in several species of herbs and shrubs. Special mention may be made of *Rosa*, *Rubus*, *Berberis*, *Pyrus*, *Sambucus*, *Hydrangea*, *Strobilanthes*, etc., among shrubs, and *Potentilla*, *Anaphalis*, *Senecio*, *Aster*, *Anemone*, *Ranunculus*, *Saxifraga*, *Sedum*, *Meconopsis*, *Primula*, *Digitalis*, *Podophyllum*, etc , among herbs. Mosses and lichens are abundant. Families like *Rosaceae*, *Compositae*, *Ranunculaceae*, *Papilionaceae*, *Rubiaceae*, *Labiatae*, *Primulaceae* (e.g *Primula* with 148 sp., mostly eastern, and *Androsace* with a few species, mostly western), etc., have a large number of representatives in this zone. The conifers occurring at higher elevations of this zone are blue pine (*Pinus excelsa*), spruce (*Picea*), silver fir (*Abies*), deodar (*Cedrus*), cypress (*Cupressus*), yew (*Taxus*), *Cephalotaxus*, *Tsuga*, juniper (*Juniperus*), etc

(*c*) **Alpine Zone** (3,500-4,500 metres). This zone extends beyond the limit of tree growth up to the perpetual snow-line, and is characterized by the dominance of small herbaceous dicotyledons spotted with low shrubs or undershrubs

(mainly species of *Juniperus*, *Betula* and *Rhododendron*). Vegetation is sparse. This zone is under the influence of extreme conditions of life, viz freezing temperature, snow-cover for the greater part of the year, powerful sunlight, strong gales, low atmospheric pressure, etc.,—conditions which reduce absorption but enhance transpiration. This being so, the vegetation shows a tendency towards xeromorphism: short growth season, stunted habit, hairy covering, thick cuticle, reduced leaves, sometimes fleshy storing water, etc. Several species of *Rhododendron* (many gregarious in habit) appear in their exquisite beauty from 3,500 metres to the alpine meadows, particularly in the eastern Himalayas As they ascend upwards to 4,500-4,800 metres their height diminishes to 0.6-0 3 metre or less. Some of the other common genera represented in this zone are *Rosa*, *Potentilla*, *Anaphalis*, *Artemisia*, *Aster*, *Chrysanthemum*, *Erigeron*, *Inula*, *Saussurea*, *Senecio*, *Aconitum*, *Anemone*, *Caltha*, *Delphinium*, *Ranunculus*, *Thalictrum*, *Saxifraga*, *Primula* (several species), *Sedum*, *Corydalis*, etc Alpine mosses and lichens are plentiful. In such a region there is a preponderance of endemic species. Further it may be noted that *Polygonum viviparum* covers a wide range (1,500- [illegible]

[illegible] snow-line: *Thalictrum alpinum*, *Ranunculus pulchellus*, *Caltha scapiosa*, *Delphinium caeruleum* and *D. viscosum*, *Potentilla microphylla*, *Saxifraga cernua* and *S. saginoides*, *Sedum himalense*, *Corydalis crassifolia*, *Rhododendron anthopogon*, and a few species of *Aster*, *Erigeron*, *Saussurea*, *etc.*

[illegible] As already stated, the eastern side is [illegible] Obviously there is some difference in the [illegible]. There are, however, many species common to both the regions. Briefly speaking the following are characteristic of the eastern region: *Pinus khasya*, *Cephalotaxus mannii*, *Abies webbiana*, *Tsuga brunoiana*, etc., among the conifers; the following genera of 'flowering' plants are more abundantly represented in the east than the west: *Rhododendron*, *Photinia*, *Primula*, *Betula*, *Saxifraga*, etc.; of the many species of *Quercus* in the east some common ones are *Q. lineata*, *Q. lamellosa*, *Q. glauca*, etc.; the following families are again better represented in the east: *Orchidaceae*, *Urticaceae*, *Primulaceae*, *Rubiaceae*, etc. The following are characteristic of the western region: *Pinus longifolia*, *P. gerardinia*, *Abies pindrow*, *Cupressus torulosa*, *Cedrus deodara*, etc., among the conifers; the following genera of 'flowering' plants are better represented in the west than in the east: *Ranunculus*, *Rubus*, *Rosa*, *Potentilla*, *Punica*, *Nepeta*, *Pistacia*, etc.; a few species of *Quercus* in the west are *Q. incana*, *Q. dilatata*, *Q. semecarpifolia*, etc.; the following families are more abundantly represented in the west: *Ranunculaceae*, *Rosaceae*, *Compositae*, *Labiatae*, *Cruciferae*, etc.

Endemism. Certain species and even genera are seen to remain confined to a small area, a small section of a country or an island from generation to generation; such species and genera are said to be endemic. They cannot migrate and spread out owing to certain natural barriers, e g. high mountains, deserts and surrounding seas. In this respect oceanic islands have a high percentage of ende-

that endemism represents the remnants of once flourishing flora, e g. tree ferns, *Ginkgo biloba*, etc. Others believe that endemic flora is of recent origin, e g. *Gentiana, Impatiens, Primula, Rhododendron*, etc. The latter view is more generally favoured. According to Chatterjee (*Studies on the Endemic Flora of India and Burma*) in India the Himalayas (temperate and alpine) and the Indian Peninsula show the largest number of endemic species, e.g. 3,169 species in the former region and 2,045 species in the latter region, while only 533 species in the general area. 'Wides' in India, i.e. those that have spread in from outside, may be approximately 4,000 species Working on the above basis endemism in India comes to almost 59% (ranging, however, according to areas, from 50-70%, the Himalayas showing the highest percentage).

PART V Cryptogams

Chapter 1 DIVISIONS AND GENERAL DESCRIPTION

Cryptogams or 'flowerless' plants are lower and more primitive plants. They form three main divisions, viz. Thallophyta, Bryophyta and Pteridophyta. Thallophyta include algae, fungi, bacteria and lichens; Bryophyta include liverworts, horned liverworts and mosses; while Pteridophyta include ferns and their allies. All these have been further divided and subdivided into smaller groups.

Reproduction. Of the three methods of reproduction, viz. vegetative, asexual and sexual, a particular plant may take to one or more methods. Vegetative reproduction commonly takes place by cell division or by fragmentation. Asexual reproduction takes place by
a different groups of plants.
fusion of two gametes, and
progressive stages—isogamy
to anisogamy to oogamy. In the primitive forms of plants there is fusion of two gametes similar in shape, size and behaviour (isogametes); the fusion of such gametes is called isogamy. In other forms the two gametes may be slightly different in size and behaviour (anisogametes); the fusion of such gametes is called anisogamy. In the advanced forms the gametes become differentiated into male (microgametes) and female (megagametes); their fusion is called oogamy. In oogamous forms the male gamete is small, motile, ciliate, active and initiative and is called an antherozoid (spermatozoid or simply sperm), while the female gamete is large, non-motile, nonciliate, passive and receptive and is called an egg (egg-cell, ovum or oosphere). In isogamous and anisogamous forms both types of gametes are discharged from the body of the plant and gametic union takes place outside the plant body; while in oogamous forms the
the
the
body of the mother plant.

Alternation of Generations.[1] The life-history of many plants (higher algae, liverworts, mosses, ferns and their allies) is complete in two

[1] Hofmeister was the first to give a clear idea in 1851 about the alternation of generations in mosses and ferns. He also tried to extend the idea to gymnosperms and angiosperms.

stages or generations, alternating with each other. These two generations differ not only in their morphological characters but also in their modes of reproduction. One generation reproduces by the asexual method, i.e. by spores, and the other by the sexual method, i.e. by gametes. The former is, therefore, called the sporophytic or asexual generation, and the latter the gametophytic or sexual generation. To complete the life-history of a particular plant one generation gives rise to the other—the gametophyte to the sporophyte and the sporophyte to the gametophyte, or to put it another way, the two generations regularly alternate with each other. This alternation of gametophyte with the sporophyte and *vice versa* is spoken of as alternation of generations.

Cytological Evidence of Alternation of Generations. In order to keep [illegible] must have a counter-stage (meiosis) involving reduction of chromosomes. It is a fact that the gametophyte always possesses half as many chromosomes as the sporophyte, or in other words, if the sporophyte bears $2n$ or diploid chromosomes the gametophyte would bear n or haploid chromosomes (n signifying the number of chromosomes). At the time of reproduction the sporophyte bears spore mother cells (each with $2n$ chromosomes). These undergo meiosis or reduction division and the chromosome number is reduced to half in the spores, evidently with n or haploid chromosomes. The spore germinates and gives rise to the gametophyte. The spore, therefore, represents the beginning of the gametophytic generation. The gametophyte, evidently with n chromosomes, in due course bears gametes. When the two gametes (male and female, each with n chromosomes) fuse to form the zygote the chromosome number is doubled, i.e. it becomes $2n$. The zygote develops into the sporophyte with $2n$ chromosomes in all its cells. The zygote, therefore, represents the beginning of the sporophytic generation which continues right up to the spore mother cells.

We may summarize the matter, therefore, by saying that spores, gametophyte, sexual organs and gametes, all with n chromosomes (i.e. the phase interpolated between fertilization and meiosis) represent the gametophytic generation, and zygote, sporophyte, sporangium and spore mother cells, all with $2n$ chromosomes (i.e. the phase interpolated between meiosis and fertilization) represent the sporophytic generation, and that haploid (n) or gametophytic generation begins with the spore and ends in the gametes, while the diploid ($2n$) or sporophytic generation begins with the zygote and ends in the spore mother cells.

In most green algae and most fungi the $2n$ or diploid phase is represented only by the zygote and not by any definite structure

developing from it, which may be regarded as a sporophyte. In them, therefore, there is no true alternation of generations. But in the higher green algae, some fungi, most brown algae and red algae, and more particularly in the higher cryptogams—liverworts, mosses, ferns and their allies—an alternation of generations is very regular. In them progressive stages in the development of the sporophyte and reduction of the gametophyte can be traced, culminating in the 'flowering' plants. In the latter the main plant body is always a sporophyte, and the gametophyte is represented only by a few cells (gymnosperms) or by a few nuclei (angiosperms).

Chapter 2 ALGAE

3

Differences between Algae and Fungi. (1) Algae are green thallophytes containing the green colouring matter *chlorophyll*. In many algae the green colour may be masked by other colours, but in all of them [illegible] rials supplied to them. They are either parasitic or saprophytic in habit. (3) The body of an alga is composed of a *true parenchymatous tissue*, but the body of a fungus is composed of a *false tissue*, or pseudo-parenchyma, which is an interwoven mass of fine delicate threads, known as *hyphae*. (4) The cell-wall of an alga is composed of true cellulose, and that of a fungus of fungus-cellulose or chitin mixed with cellulose, callose, pectose, etc., in different proportions. [illegible]

In structure both the groups may be unicellular, multicellular, filamentous or thalloid, and reproduction in them may take place vegetatively by cell division or by detachment of a portion of the mother plant, or asexually by spores, or sexually by gametes.

Classification of Algae (20,000 sp.)

Class I Myxophyceae or Cyanophyceae or blue-green algae (1,500 sp), e g. *Gloeocapsa, Oscillatoria, Nostoc, Rivularia,* etc.

Class II Euglenophyceae (350 sp), e g. *Euglena.*

Class III Chlorophyceae or green algae (6,500 sp.). Order 1. Volvocales, e g. *Chlamydomonas, Pandorina, Eudorina* and *Volvox.* Order 2. Chlorococcales, e g. *Chlorococcum, Protosiphon* and *Hydrodictyon.* Order 3. Ulotrichales, e.g. *Ulothrix, Chaetophora, Coleochaete* and *Protococcus.* Order 4. Conjugales, e.g. *Spirogyra, Zygnema* and desmids (e g. *Cosmarium*). Order 5. Oedogoniales, e g. *Oedogonium.* Order 6. Siphonocladiales. e g. *Cladophora* Order 7. Siphonales, e.g. *Vaucheria* and *Caulerpa.*

Class IV Charophyceae (215 sp.), e.g. *Chara* and *Nitella.*

Class V Bacillariophyceae or diatoms (5,300 sp.).

Class VI Phaeophyceae or brown algae (about 1,000 sp.), e.g. *Ectocarpus, Fucus* and *Sargassum.*

Class VII Rhodophyceae or red algae (about 3,000 sp.), e.g. *Polysiphonia* and *Batrachospermum.*

CLASS I | CYANOPHYCEAE or MYXOPHYCEAE or blue-green algae | 1,500 sp.

General Description. Cyanophyceae or Myxophyceae or blue-green algae are a small group of primitive algae characterized by the presence of a blue pigment *phycocyanin* in addition to chlorophyll (together making a blue-green colour), simple construction of the plant body, not clearly differentiated protoplast, and simple method of reproduction. Some species are truly unicellular, while in others the daughter cells after divisions adhere together to form a chain of cells (filament) or a flat or spherical colony. A great majority of them are freshwater dwellers and often abundantly found in almost every stagnant pool of water, wet ground and as road slime after rains. The cell structure is of primitive type. There is no definite nucleus nor any plastid, and the protoplast is differentiated into a peripheral coloured zone—the chromoplasm, and an inner colourless portion—the central body (see FIG. 2C). The cell-wall is made of cellulose and pectic compounds. Carbohydrate occurs in the form of glycogen, starch being altogether absent. A gelatinous sheath is a common feature in most of them. Some filamentous forms, particularly *Oscillatoria,* show a slow spontaneous movement. Blue-green algae never reproduce sexually nor do they bear any kind of ciliated bodies. The common methods of vegetative reproduction are cell division in unicellular forms, breaking up of the colony in colonial forms, and fragmentation of the filament into short pieces called hormogonia [illegible] with transparent contents and thickened walls may be seen; these are called heterocysts (see p. 376).

Origin and Relationship of Cyanophyceae. Cyanophyceae or blue-green algae are supposed to have originated from some non-ciliate unicellular ancestor. Cyano-

phyceae is a very primitive group and has not given rise to higher forms of plants, but has remained confined within its own group. Its primitive nature is evident from the simple construction of the plant body and lack of organized protoplast (cytoplasm, nucleus and plastids). Further evidence lies in the fact that sexual reproduction is altogether wanting and so also the asexual reproduction by ciliated bodies (zoospores). Cyanophyceae has, however, some resemblance to Rhodophyceae in sometimes possessing *phycoerythrin* (the red pigment of the latter) and in lacking ciliated motile cells at any stage of its life-history. Blue-green algae seem to be related to bacteria, both being ancient groups with some similarities in characters.

1. *GLOEOCAPSA*

Occurrence. *Gloeocapsa* (FIG. 1) represents a simple primitive form of unicellular blue-green algae. It is commonly found on wet rocks, wet ground, in a pool of water, often in laboratory aquaria, forming small masses of jelly. A small such mass examined under a microscope reveals a large number of single cells or small colonies of cells, oval or spherical in shape, lying embedded in a mucilaginous matrix.

Structure. A single cell, more or less spherical in shape, represents a *Gloeocapsa* plant. The protoplast of the cell is generally differentiated into two regions: a blue-green peripheral region with chlorophyll and phycocyanin diffused through it—the *chromoplasm*—and a central region with a mass of chromatin granules constituting an incipient nucleus—the *central body*. The plant is always unicellular but often 2 to 4, sometimes several, daughter cells are held together in a colony by the mucilaginous sheath which occurs in concentric layers surrounding the individual cells as well as the whole colony. Mucilage is always derived from the walls of the individual cells.

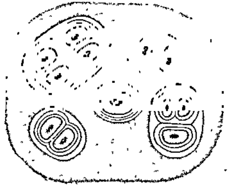


FIG. 1. *Gloeocapsa*—a cell and four colonies—embedded in gelatinous matrix.

Reproduction. *Gloeocapsa* reproduces vegetatively only by the process of cell division. In this process the central chromatin matter divides first into two parts, and this is followed by the formation of a ring-like wall across the cell and its growth inward dividing the cell into two. Each daughter cell secretes its own mucilaginous sheath, grows and finally behaves as a new plant. Two or more such cells are frequently held together in a colony in a common

mucilaginous matrix secreted by the individual cells. Sometimes a few species form thick-walled resting spores.

2. *OSCILLATORIA* (*100 sp.*)

Oscillatoria (FIG. 2A) is a dark blue-green alga. It consists of a slender, unbranched, cylindrical filament. It commonly occurs in ditches, in a shallow pool of water, wet rocks and walls, and in sewers. Filaments of *Oscillatoria* are entangled into masses which float in water. Each filament is made up of numerous short cells. The individual cells are the *Oscillatoria* plants, and the filament is regarded as a colony. All the cells are alike except the end cell which

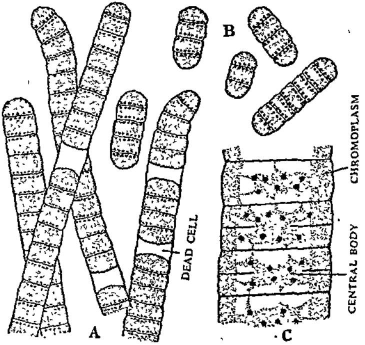


FIG. 2. *Oscillatoria*. *A*, filaments; *B*, hormogonia; and *C*, a portion of the filament magnified.

is usually convex, and there is no differentiation between the base and the apex. Here and there some dead and empty cells occur in some of the filaments. The protoplast of each cell is differentiated into two regions: a coloured peripheral zone—the **chromoplasm**, and an inner colourless zone—the **central body** (FIG. 2C). The colour is due to the presence of chlorophyll and phycocyanin (a blue pigment) which diffuse through the chromoplasm and are not associated with any kind of plastids. Both regions are granular in nature with various spherical or irregular inclusions which are mainly food grains, particularly glycogen and proteins. There is no true nucleus. The

central body, however, is regarded as an incipient nucleus with only some chromatin but without nuclear membrane and nucleolus. Cell division takes place in one direction only. Each filament remains enveloped in a thin mucilaginous sheath. Under the microscope a slow swaying or oscillating movement of the filaments with ends tossing from side to side may be distinctly seen. The filaments may sometimes exhibit a twisting or rotating motion. This is a characteristic feature of *Oscillatoria*.

Reproduction. In blue-green algae reproduction takes place vegetatively by cell division or by fragmentation of the filament, or asexually by spores. Gametes and zoospores are altogether absent in them. In *Oscillatoria* the filament breaks up into a number of fragments, called **hormogonia** (FIG. 2B). Each hormogonium consists of one or more cells and grows into a filament by cell divisions in one direction. The hormogonium has a capacity for locomotion.

3. *NOSTOC* (*29 sp.*)

Occurrence. *Nostoc* (FIG. 3) is a common blue-green alga of filamentous form. Species of *Nostoc* may be terrestrial or aquatic, and generally occur in ponds, ditches and other pools of water, and also in the damp soil as little, somewhat firm, masses of jelly. A few

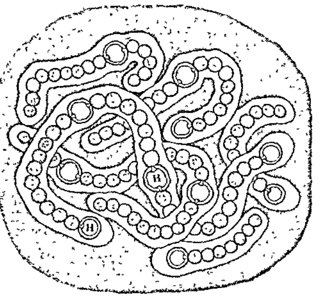


FIG. 3. *Nostoc* filaments embedded in gelatinous matrix. Note the heterocysts (*H*) *with the* polar nodules.

species are endophytic in habit occurring in the intercellular cavities of plants like *Anthoceros, Lemna*, root of *Cycas*, etc. Some lead a symbiotic life with a fungus forming a lichen.

Structure. Each gelatinous mass contains numerous slender filaments

which under the microscope look very like strings of beads. The filaments are interwoven forming an intricate mass. Each filament is unbranched and consists of a colony of cells like beads in a chain, and is often invested by a gelatinous sheath of its own, in addition to the gelatinous matrix in which the tangled mass of filaments remains embedded. The sheath may be colourless or slightly tinged. The filament minus the sheath is commonly called a *trichome*. Each cell of the filament is more or less spherical or oval (sometimes barrel-shaped or somewhat cylindrical) in shape and blue-green in colour. The constitution of the cell is very much like that of *Gloeocapsa*. The filament increases in length by cell division in one plane only. The divided cells grow and round off, and the filament elongates and appears like a beaded chain. A characteristic feature of *Nostoc* is the presence of some enlarged vegetative cells, at frequent intervals, with thickened walls and transparent contents; these are called heterocysts. At the two poles of each heterocyst there are two pores, one at each end, through which cytoplasmic connexion is maintained between the heterocyst and the adjacent vegetative cells. In the terminal heterocyst, however, only one such pore is formed. In any case each pore is later closed by a button-like thickening of the wall —the *polar nodule*. The function of the heterocyst is not definitely known (see below).

Reproduction. *Nostoc* reproduces vegetatively by fragmentation, and sometimes asexually by resting cells (spores), called akinetes.

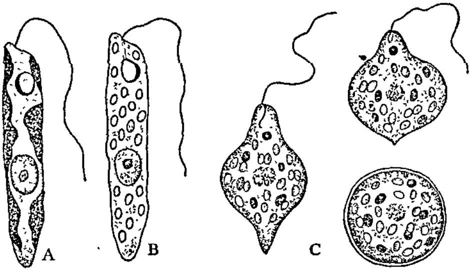
Fragmentation. In vegetative reproduction the filament breaks up into a number of short segments, called hormogonia. Each hormogonium by repeated cell divisions in one direction gives rise to a long filament. A large number of such daughter filaments may be seen in the gelatinous matrix. The fragmentation of the filament into hormogonia takes place at the junction of the heterocyst and the adjoining cell. The function of the heterocyst is otherwise not definitely known. It may, however, sometimes act as a spore. It has also been suggested that the heterocyst is a food storage cell.

Akinetes. In a few species of *Nostoc* under unfavourable conditions, e.g. winter or drought periods, certain vegetative cells of the filament become enlarged and thick-walled containing reserve food; these are called resting cells (spores) or akinetes and may be produced singly or in a chain. An akinete is regarded as a modified vegetative cell [illegible] distinct [illegible] akinetes [illegible] tion in it, either close to or away from the heterocyst. Later under favourable conditions each germinates and gives rise to a *Nostoc* filament.

CLASS II | EUGLENOPHYCEAE | over 18 sp.

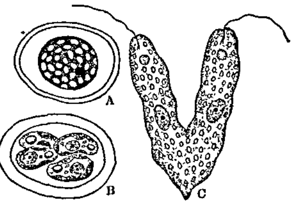
EUGLENA (*over 18 sp.*)

Euglena (FIG. 4) is a most simple unicellular organism from which evolution of the higher forms of plants has possibly started. It



Euglena. FIG. 4. *A*, green form; *B*, colourless (saprophytic) form; *C*, various forms (three shown) assumed by a single cell.

belongs to the group Flagellatae in which the organisms are difficult to refer to the kingdom of plants or of animals. It grows in large numbers in polluted water containing organic substances, and colours it bright green. It is a single-celled, naked, free-swimming organism, elongated in shape, with one end blunt and the other end tapering. It is provided with a single cilium, i.e. a long, slender, whip-like projection, which vibrates and helps the plant to swim in water. It can also crawl by changing its shape (FIG. 4C). The protoplast contains a central nucleus, several green plastids, a contractile vacuole contracting and expanding in a few seconds, and a red spot near the blunt end, called the *eye spot*



Euglena. FIG. 5. *A*, resting spore or cyst; *B*, four daughter cells formed by division of the cyst; *C*, longitudinal splitting of *Euglena* cell.

(FIG. 4C). It feeds itself by photosynthesis and at the same time it ingests solid particles as food from the surrounding water. When grown in the dark it loses its colour and leads a saprophytic life, *obtaining* nourishment from the aquatic medium in which it grows (FIG. 4B). It does not contain starch as the product of carbon-assimilation.

Reproduction. There is no sexual mode of reproduction in this plant. It multiplies by dividing longitudinally into two, the nucleus taking the initiative in the process (FIG. 5C). When the food supply falls short the protoplasmic contents contract and become surrounded by a thick wall which can then resist unfavourable conditions. This is known as the cyst or resting spore (FIG. 5A). The cyst germinates under favourable conditions when the wall becomes mucilaginous and the protoplast divides into 2, 4 or more bodies (FIG. 5B). The divided bodies are set free as naked, unicellular organisms.

CLASS III | CHLOROPHYCEAE or green algae | 6,500 sp.

General Description. Chlorophyceae or green algae are characterized by the presence of green pigment or chlorophyll located in definite plastids (chloroplasts). They are mostly freshwater algae, but some species are terrestrial and not a few are marine. Green algae exhibit a variety of forms—unicellular or colonial being motile or non-motile, multicellular being thalloid or filamentous; some species are coenocytic. The protoplast in all Chlorophyceae is well organized with a definite nucleus (commonly one in each cell or numerous in a coenocyte) and one or more distinct chloroplasts. According to species or genera the chloroplasts vary in shapes and also in sizes—

[illegible]

with often a layer of pectose external to it. Gelatinous sheath may or may not be present. Most unicellular and colonial forms are provided with whip-like structures, called *cilia*—often 2, sometimes 4 or many—for motility of cells or colonies. In Chlorophyceae the cilia are of uniform length and always formed at the anterior end of the cell. In higher forms of Chlorophyceae the cilia are restricted to the reproductive bodies only—zoospores and zoogametes. Primitive forms of Chlorophyceae have two or more contractile vacuoles and a small eye spot (see FIG. 6A).

Reproduction. Vegetative reproduction takes place commonly by cell division or by fragmentation. Asexual reproduction takes place by spores which are of varying types: a motile, ciliate spore is called a zoospore; a non-motile, non-ciliate spore with a distinct

wall of its own but produced within a mother cell is called an aplanospore (abortive zoospore); and a vegetative cell acting as a spore having no wall of its own—the wall of the mother cell acting as the wall of the spore—is called an **akinete** (modified vegetative cell). Sexual reproduction takes place by **isogamy**, **anisogamy** or **oogamy** according to species (see p. 380). Whatever be the mode of sexual reproduction some species are **homothallic** (i.e. the pairing gametes come from the same parent) or **heterothallic** (i.e. the pairing gametes come from two separate parents). In many green algae it has been observed that a gamete grows *parthenogenetically* (i e. without fusion with another gamete) into a new plant; the gamete thus behaves as a spore and is called **parthenospore** or **azygospore**. Sometimes, as in *Spirogyra*, the gamete is without cilia and is called **aplanogamete**.

Origin and Evolution of Sexuality in Chlorophyceae. The vegetative method of reproduction is the most primitive method of multiplication of individual plants. Asexual reproduction by zoospores appeared later in the early (lower) Chlorophyceae, possibly as a means of rapid multiplication. Sexual reproduction appeared still later and continued right up to the highest division of the plant kingdom, evidently to achieve something not obtained by the other methods. This something is predominantly protection rather than reproduction as the thick-walled zygote—the result of the sexual act—is better fitted to withstand unfavourable conditions of the environment prior to its starting a new life. Sexual reproduction has other advantages too. It may be noted that when conditions are favourable for vegetative activity neither spores nor gametes are produced; when conditions are less favourable asexual cells or spores are produced; and when the plant is approaching the end of its life or when the conditions are very unfavourable sexual cells or gametes are produced. The mode of reproduction is thus greatly influenced by the changing environment and age of the plant.

The basic fact with regard to the origin of sexuality in Chlorophyceae is that it appeared as a modification of the older asexual method, and is directly correlated with the origin of the sexual cells or gametes for the first time from the asexual cells or spores (zoospores). The gametes because of their smallness in size due to repeated divisions have lost the power of functioning individually; they have thus developed some kind of mutual attraction and freely come together in pairs and fuse. This is the earliest indication of sexuality. It may then be rightly said that gametes are derived from spores (zoospores). It is also seen that spores and gametes are similar in several members of Chlorophyceae, e g. *Chlamydomonas*, *Ulothrix*, *Oedogonium*, etc., excepting that the latter are smaller in size and more numerous.

Once sexuality appeared it established itself, and its evolution

through isogamy to anisogamy to oogamy based on the differentiation of sexual cells and sexual organs proceeded towards a high degree of complexity, possibly towards a state of perfection through successive and progressive stages. In the simple and primitive forms of Chlorophyceae there is fusion of two gametes (zoogametes) similar in shape and size; this is called **isogamy**. The next stage in the evolution of sexuality is what is called **anisogamy**; here a slight difference is noticed in the size of the gametes or in their behaviour—the first indication of differentiation into male and female. A complete differentiation of gametes and gametangia into male and female is found in the advanced forms of Chlorophyceae. The union of such differentiated gametes is called **oogamy**. Throughout Chlorophyceae the gametangia have, however, remained single-celled. It is also significant that there has been parallel progress in the origin and evolution of sexuality along the same evolutionary lines through the different orders of Chlorophyceae following divergent trends of evolution. Some representative types of Chlorophyceae may now be considered to illustrate the above.

Chlamydomonas (see FIGS. 6C & 7B). The simplest type of gamete-formation is found in *Chlamydomonas*. Here the vegetative cell div
rep
64 [illegible]
The zoospores and gametes are similar in structure but the latter are smaller and more numerous. This is suggestive of the fact that gametes are derived from zoospores and that sexuality has its *origin* in the transformation of the asexual zoospores into sexual gametes. This is a case of isogamy.

Ulothrix (see FIG. 17C & C). *Ulothrix* is another case to illustrate the origin of sexual cells or gametes from asexual cells or zoospores. It produces zoospores of different sizes—large with 4 cilia, medium with 2 or 4 cilia, and small with 2 cilia. The large zoospore germinates into the normal filament; the medium one into a slow-growing filament; while the small one germinates, if at all, into a short filament. The small ones, however, freely come together in pairs and fuse into a zygote which then germinates normally. Small spores not being able to function individually behave as gametes. Transition from spores to gametes and, therefore, from an asexual to a sexual condition is thus clear. A *reproductive unit is thus a spore or a gamete according to its behaviour*, or in other words, the origin of sex is correlated with the behaviour of the spore as a gamete.

Spirogyra and *Zygnema*. In these the special feature is that the gametes are without cilia and are called *aplanogametes*. In some species of *Zygnema* the gametes are truly isogamous, the two gametes meeting and fusing in the conjugation tube; while in other species of *Zygnema* (see FIG. 27 B-C) and in all species of *Spirogyra* (see FIG. 21)

the gametes are morphologically isogamous but physiologically anisogamous. One gamete (male) is actively amoeboid and the other gamete (female) is passive. This order (Conjugales) does not form spores (zoospores) for asexual reproduction. But sometimes when conjugation fails the protoplast (gamete) of a cell behaves as a spore and is called the *azygospore*.

ovum—borne respectively by antheridium and oogonium which are only certain cells of the parent filament. Here the zoospores and the antherozoids, each provided with a ring of cilia, are similar in appearance excepting that the latter are smaller in size.

Vaucheria (see FIGS. 34 C-D & 35 A-C). This reproduces, as in the previous case, by a solitary zoospore, and by highly differentiated male and female gametes and gametangia (oogamy). Here the antherozoids are quite distinct from the zoospores. The former are very minute, biciliate and produced in large numbers; while the latter are large, solitary and multiciliate. The antheridium and the oogonium bearing antherozoids and ovum respectively are produced laterally by the vegetative filament or they occur on special short branches borne by the parent filament.

Origin and Evolution of Chlorophyceae. It is presumed that Chlorophyceae or green algae have evolved from some motile (ciliate) unicellular ancestor of the type of *Chlamydomonas*. Several orders of Chlorophyceae seem to have evolved

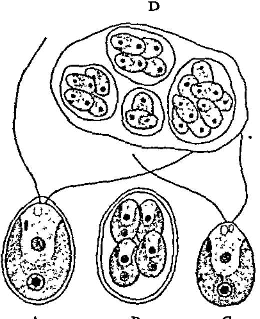
zoospores, and still later by the sexual method in progressive stages—isogamy to anisogamy to oogamy.

1. *CHLAMYDOMONAS* (*43 sp.*)

Occurrence. *Chlamydomonas* is a unicellular green alga found in ponds, ditches and other pools of stagnant water. A few species are found in snow in different regions forming blood-red patches due to the development of a red pigment by such species.

Structure. *Chlamydomonas* cells (FIG. 6A) are unicellular, usually

spherical or oval in shape, with a thin wall. *Chlamydomonas* may be regarded as an intermediate form between the flagellate algae and the higher algae. The protoplasm at the anterior end of the cell is clear; it gives off two cilia and contains two contractile vacuoles which are pulsating in nature, undergoing alternate expansion and contraction. These may be respiratory or excretory in function. There is a lateral orange or red pigment spot, commonly called the *eye spot*. This is sensitive to different intensities of light. In the posterior region there is a single large cup-shaped chloroplast with a pyrenoid in it. The pyrenoid consists of a central protein body surrounded by numerous minute starch grains. There is a nucleus more or less centrally placed. By the lashing of the cilia the cells quickly move about in water.



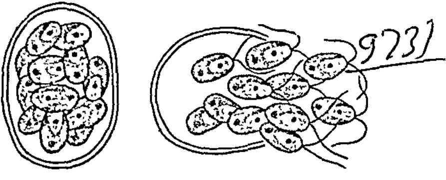
ual method; *C*, a zoospore after escape; *D*, palmella stage.

Asexual Reproduction. *Chlamydomonas* reproduces asexually by zoospores. In the formation of the zoospores the cilia of each cell are withdrawn, and the contents divide into 2, 4 or 8 cells, seldom more (FIG. 6B). The cells grow, develop two cilia each, and become motile zoospores. The wall of the mother cell dissolves and the zoospores are set free (FIG. 6C).

Palmella Stage. Under certain conditions the daughter cells instead of forming zoospores divide repeatedly into numerous cells. Their walls become gelatinous, and the cells are held together in colonies by the gelatinous envelope of the mother cell. Thus numerous colonies are seen to lie embedded in a gelatinous matrix. This is known as the palmella stage (FIG. 6D). When the conditions are favourable the cells develop cilia, swim out of the gelatinous matrix, and become motile again.

Sexual Reproduction. Sexual reproduction takes place by motile ciliate gametes which are formed in the same way as the zoospores

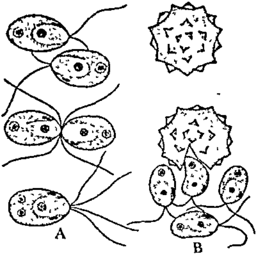
and are also alike excepting that they are somewhat smaller in size and more numerous—16, 32 or 64, or even more (FIG. 7). All gametes



A B

Chlamydomonas. FIG. 7. *A*, gametes formed; *B*, gametes escaping.

are similar and are called *isogametes*, and their fusion is known as *isogamy*. Gametes of different parents usually conjugate in pairs (FIG. 8A). A *zygospore*—the product of fusion of two similar gametes—is formed. Their ciliate ends conjugate first. Soon after fusion the cilia are withdrawn and the zygospore clothes itself with a thick wall (FIG. 8B). It undergoes a period of rest, and then its contents divide and form 2 or 4 motile daughter cells (FIG. 8B). They grow in size, escape from the mother cell, and become individual motile *Chlamydomonas* cells.



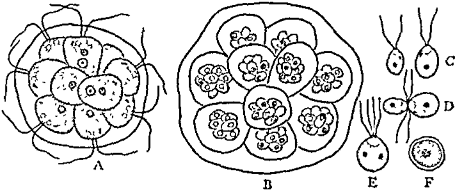
Chlamydomonas. FIG. 8. *A*, free swimming gametes and conjugation; *B*, (*top*) a resting zygote; (*bottom*) four cells formed from the zygote.

It may be noted that in *Chlamydomonas* gametes are mostly alike (isogametes), while there are cases showing slight differentiation of gametes (anisogametes), Further, similarity of gametes and zoospores is suggestive of the origin of sexual cells (gametes) from asexual cells (zoospores) by transformation of the latter into the former.

2. *PANDORINA* (*3 sp.*)

Pandorina (FIG. 9) forms small oval colonies of usually 16 biciliate cells (sometimes 4, 8 or 32 cells) which are similar and which are

arranged to form a hollow sphere, i.e. the cells lie around a small central cavity. The colonies lie embedded in a gelatinous matrix. The cells being close together in the colony become laterally compressed. The individual cells of the colony are like those of *Chlamydomonas*. The colony is propelled in water by the vibration of the two widely divergent cilia of each cell.



Reproduction. *Pandorina* reproduces both asexually and sexually. In asexual reproduction the individual cells of the colony simultaneously divide, each producing usually 16 daughter cells in a colony or as many cells as are present in the mother colony. Later the new (daughter) colonies escape after the breakdown of the mother cells and swim away through the gelatinous envelope. In sexual reproduction the cells of the colony form biciliate gametes, 16 or 32 in number, exactly in the same way as in asexual reproduction. The gametes are similar in shape but dissimilar in size, some slightly larger and less active than others. They escape in groups but sooner or later they separate into free individual gametes and swim about. Soon the dissimilar gametes (anisogametes) fuse in pairs, the process being known as anisogamy. This anisogamy, it may be noted, becomes more pronounced in *Eudorina*. The result of fusion is a zygote. It soon settles down and forms a wall round itself. Later it divides and produces four zoospores, out of which one divides and forms a new colony; the remaining three degenerate.

3. *EUDORINA* (*4 or 5 sp.*)

Pandorina, *Eudorina*, *Volvox* and a few others are colonial algae in which the cells lie in a hollow mucilaginous sphere. Each colony, known as *coenobium*, consists of 16 cells in the case of *Pandorina*, 32 cells in the case of *Eudorina* and a few hundreds, often many thousands, in the case of *Volvox*, lying embedded in a spherical mucilaginous matrix.

male and female. The vegetative cells of the female colony enlarge to some extent, lose their cilia and come to lie near the surface of the mucilaginous sphere (11E). Each such cell is a single female gamete. The cells, often not all, of the male colony divide successively giving rise to a packet of 64 male cells (11B). The packet of cells *moves out of the colony and swims as a unit to the female colony* (11C-D). The packet then splits up into individual male gametes or spermatozoids, as shown in (11E). The spermatozoids are more or less spindle-shaped and provided with two cilia. They swim into the female colony (11E) and each fuses with a female gamete to form an oospore. It is to be noted that two dissimilar gametes (male and female) fuse in pairs; so this is a case of *oogamy*. Several such oospores are formed. They remain in the female colony until the decay of the latter has set in. In the germination of the oospore its contents form one zoospore together with 2 or 3 smaller hyaline bodies (possibly degenerated zoospores). The zoospore divides repeatedly and soon forms a colony.

4. *VOLVOX* (*over 12 sp.*)

Volvox (FIG. 12) is a freshwater, colony-forming, free-swimming, green alga occurring in ponds and other pools of water during and after rains. It often appears in abundance colouring the water green,

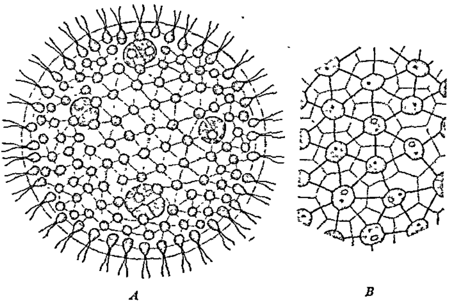


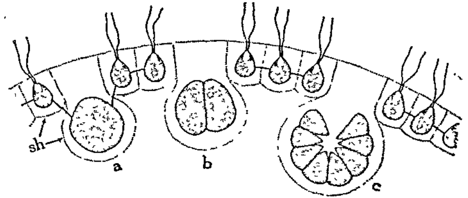
FIG. 12. *Volvox*. *A*, a colony showing vegetative cells connected by cytoplasmic strands, four colony-forming cells (including two daughter colonies) and outer sheath; *B*, a portion of a colony (magnified) showing vegetative cells connected by cytoplasmic strands (thick lines) and polygonal sheaths (dotted lines).

particularly in the spring, and then abruptly disappears in the summer. During the rest of the year it lies dormant in the zygote stage.

Among the Volvocales this plant has reached the highest degree of colony formation. As a matter of fact each colony or coenobium (*koinos*, common; *bios*, life), as it is called, consists of a few hundreds to several thousands (500-40,000) of cells which are so arranged in a peripheral layer as to form a hollow sphere (FIG. 12A) containing water or a dilute solution of a gelatinous material. Each cell (FIG. 12B) of the colony has a gelatinous sheath of its own, and at the same time the cells are held together in a colony by the sheaths secreted by the individual cells. The cells are connected by delicate but distinct strands of cytoplasm. The colonies, approximately 1 mm. in diameter, sometimes up to 2 mm., swim about freely in water. Each *Volvox* cell is very much like that of *Chlamydomonas*.

A mature colony (FIG. 12A) shows two kinds of cells: numerous small vegetative cells and also a few (5-20) large cells among them. A vegetative cell has two cilia protruding outwards and vibrating, 2 to 5 contractile vacuoles, a central nucleus, a cup-shaped or plate-like chloroplast with one pyrenoid, and an eye spot. The vegetative cells do not divide. The larger cells of the colony are the reproductive cells. These cells may behave exclusively as asexual cells or as sexual cells. Normally they act as asexual cells in the beginning of the season, and as sexual cells at the close of the season.

Asexual Reproduction (FIG. 13). The above enlarged cells (called gonidia) of the mother colony, after retracting their cilia and pushing



Volvox. Asexual Reproduction. FIG. 13. Formation of a daughter colony within a mother colony; *a*, an enlarged vegetative cell (gonidium); *b*, the same after first division; *c*, a young daughter colony developed from it; *sh*, sheath. *Redrawn after Fig. 12 in* Cryptogamic Botany, Vol. I *by G. M. Smith by permission of McGraw-Hill Book Company. Copyright 1938.*

back to the posterior side, divide and re-divide in the longitudinal plane and give rise to a large number of cells in one plane, thus forming new young daughter colonies within the mother colony.

When cell divisions cease the cells turn round, develop cilia and

they escape from their imprisoned state by a rupture of the membrane of the mother colony or through a pore in it, and swim away as independent colonies

Sexual Reproduction (FIG 14). Sexual reproduction is oogamous in *Volvox*. In the monoecious species both types of gametes (male and female) are borne by the same colony (*homothallic*), while in the dioecious species they are borne by separate colonies (*heterothallic*).

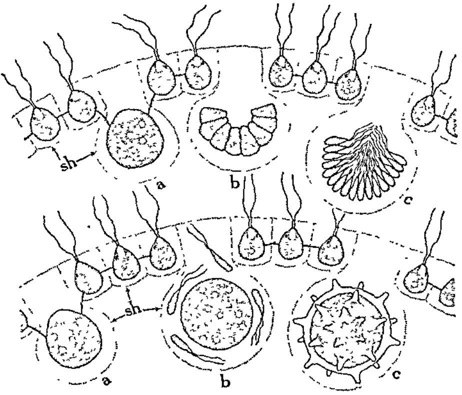


Fig. 13 in Cryptogamic Botany, Vol. I *by G. M. Smith by permission of McGraw-Hill Book Company. Copyright 1938.*

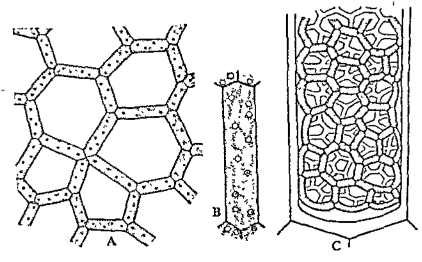
These gametes are borne by certain enlarged cells called gametangia (gamete-bearing cells) which lie in the posterior side of the colony. Some of these cells are antheridia or male reproductive organs, the protoplast of which divides many times and produces a cluster of minute, biciliate, male gametes called the antherozoids or sperms

(FIG. 14A); while other cells are oogonia or female reproductive organs, the protoplast of which forms a single, large, female gamete called egg or ovum (FIG. 14B). The egg is large, passive and non-motile, while the sperms are very minute, active and motile. The latter may be in a plate-like colony escaping from the mother colony as a unit, or they may be arranged to form a hollow sphere. In the former case the unit as it approaches an egg breaks up into individual sperms, and in the latter case the sperms are liberated singly. The mode of fertilization is oogamous. The sperms swim and enter through the gelatinous sheath into the oogonium lying in the mother colony, and one of them finally fuses with the egg (FIG. 14B*b*). Thus fertilization is effected.

Zygote. After fertilization the zygote clothes itself with a thick spiny wall and turns orange-red (FIG. 14C). It is set free from the mother colony only after the decay or disintegration of the latter. The zygote sinks to the bottom of the pool of water, and then after a period of rest it germinates with the approach of the favourable season. The protoplast of the zygote undergoes reduction division prior to germination. In some species the protoplast of the zygote divides and forms a new colony directly; in others it forms a single biciliate zoospore which escapes by the rupture of the zygote wall and swims away. The free-swimming zoospore divides and forms a new colony.

5. *HYDRODICTYON*

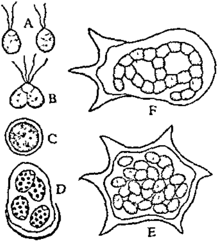
Hydrodictyon (FIG. 15 A-B) is a common, freshwater, net-like, green alga. The net, a fairly big one, sometimes growing up to 25 cm. or



Hydrodictyon FIG
(magnified); *C*, a

so, and hollow within, freely floats on water. The plant body (net) consists of elongated cylindrical cells which anastomose to form a sac-like net. The cells are at first uninucleate and contain a single chloroplast with a pyrenoid but later they become multinucleate and contain a reticulate chloroplast with many pyrenoids. *Hydrodictyon* has reached the highest degree of non-motile colony-formation.

Reproduction. Asexual reproduction (FIG. 15C) takes place through zoospores. The protoplast of a vegetative cell produces a large number of zoospores (7,000-20,000), which swim for a time within the mother cell. Soon they come together and form a new net within the mother cell. After the disintegration of the mother cell the new (daughter) net grows into an adult one. **Sexual reproduction** (FIG. 16) is isogamous. A vegetative cell forms 30,000-100,000 minute,



Hydrodictyon. FIG. 16.
A, isogametes;
B, conjugation;
C, formation of zygote;
D, zoospores escaping into a vesicle from the zygote;

numerous zoospores;
F, a young net formed by rearrangement of zoospores.

biciliate gametes (isogametes). They escape through an opening of the mother cell, and fuse in pairs. The zygote, thus formed, divides by meiosis to form four biciliate zoospores. Each zoospore at first grows into a thick-walled polyhedral case. Its protoplast undergoes rest for some months and then divides to form a large number of small zoospores which soon escape into a vesicle. Within the vesicle the zoospores rearrange themselves in such a way as to form a short and irregular net which soon grows up into the adult size.

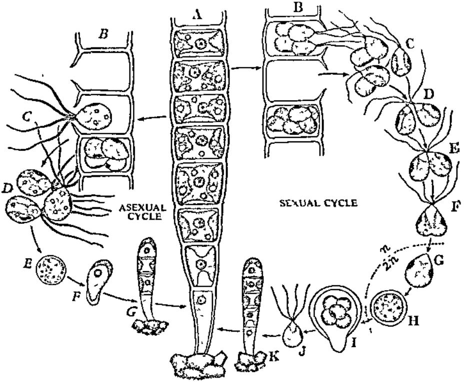
6. *ULOTHRIX* (*30 sp.*)

Ulothrix (FIG. 17) is a green filamentous alga occurring in fresh water in ponds, ditches, water-reservoirs, horse- or cow-troughs, slow streams, etc., particularly in the spring; a few species grow in the sea. The filament of *Ulothrix* is unbranched and consists of a single row of more or less rectangular cells. It is fixed to the substratum or to any hard object in water by the basal elongated colourless cell called the *holdfast*. The filament, if detached, may float freely on water.

Each cell of the filament contains a nucleus and a peripheral band-like chloroplast with entire or lobed margin. Usually there are many (sometimes one or few) *pyrenoids* lying embedded in the chloroplast. These are rounded protein bodies with a starchy envelope.

Reproduction takes place asexually by zoospores, sexually by gametes, and vegetatively by fragmentation of the filament.

Asexual Reproduction. (1) Zoospores with 4 cilia (megazoospores) are produced for the process of asexual reproduction by division of the protoplast of any cell of the filament except the holdfast. They are larger than the gametes but produced in fewer numbers—2, 4, or 8 or sometimes even 1, rarely as many as 16 or even 32—in each



cell. Each zoospore is more or less pear-shaped and contains a distinct red *eye spot* on one side, a pulsating vacuole close to the flagellate end, and a large chloroplast. The zoospores escape by an opening in the lateral wall of the cell and swim briskly about in water for some hours or even for a few days. Then they come to rest and

attach themselves to any hard object in water by their colourless end. Cilia are withdrawn and a cell-wall is formed round each zoospore. Then it germinates directly into a new filament. (2) Sometimes smaller zoospores (but bigger than gametes), called **microzoospores**, are produced in the filament, and they possess either two cilia or four cilia. Either they germinate directly into new *Ulothrix* filaments like the megazoospores, or they fuse in pairs like the gametes. This indicates that the origin of gametes lies in zoospores. (3) Sometimes the whole protoplast of a cell may round itself off and form a thick-walled spore known as the **aplanospore** (non-ciliate, non-motile, modified zoospore).

Sexual Reproduction. Sexual reproduction is isogamous consisting in the fusion of two similar biciliate gametes (*isogametes*). The gametes may be formed in any cell of the filament except the holdfast They are smaller than the zoospores, biciliate and may be 8, 16, 32 or 64 in number in each cell. Each gamete possesses a red *eye spot* and a chloroplast band The gametes are set free from the cell exactly in the same way as the zoospores and they swim about in water with the help of their cilia for some time. Two gametes coming from two different filaments (*heterothallic*) get entangled by their cilia and gradually a complete fusion (conjugation) of the two takes place laterally. Cilia are withdrawn towards the close of the process, and the fusion product still moves for a while but soon comes to rest. It rounds itself off and clothes itself with a thick cell-wall, and forms into a **zygospore**. After a period of rest the zygospore germinates into a unicellular *germ plant* which produces zoospores or aplanospores—4 to 16 in number. They are quadriciliate (zoospores) or nonciliate (aplanospores) and each develops into a new plant. If fusion fails, each gamete may behave as a zoospore. It withdraws the cilia, rounds itself off and clothes itself with a cell-wall. After a dormant period it germinates directly into a new [illegible] *haploid* chromosomes. [illegible] out the life of *Ulothrix* plant.

Vegetative Reproduction. This takes place by fragmentation of the filament into short pieces, each consisting of a few cells. Each piece or fragment grows into a long filament by transverse divisions of cells and their enlargement.

Note. In *Ulothrix* we get a very early indication of the sexual differentiation which becomes so pronounced in the higher plants. The behaviour of gametes or sexual cells and zoospores or asexual cells suggests that the former were originally derived from the latter. The gametes are similar in appearance, but not in their behaviour. The passive one may be regarded as the egg-cell or female gamete, and the active one as the male gamete. *Ulothrix* thus shows the beginning of sexual differentiation.

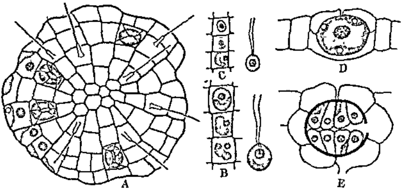
7. *COLEOCHAETE* (*10 sp.*)

Coleochaete (FIG. 18) is a small green alga. It is found in fresh water commonly attached to leaves and stems of some aquatic 'flowering' plants.

Structure. *According to species the plant body may consist of* branched filaments made of rows of cells or a disc-like thallus with lobed margin (*A*), the thallus consisting of filaments radiating from a common centre; the filaments are so close or adpressed together as to simulate a continuous disc. In certain species the filaments grow vertically from a cushion-like prostrate base. The disc-like thallus appears like a pinhead, varying in size from 2-5 mm., and is one layer of cells thick. Many of the cells give out long slender hair-like bristles, called *setae*, with a gelatinous sheathing base and a linear thread of cytoplasm within. The seta is an outgrowth of the wall formed at a pore in it (wall). Each cell has a nucleus and a *parietal chloroplast, the latter with 1 or 2 pyrenoids. The growth is* apical or marginal.

Reproduction. *Coleochaete* reproduces both asexually and sexually.

Asexual reproduction takes place by **zoospores** (*B*). Any vegetative cell may act as a zoosporangium, producing a single relatively



(in section) showing a group of cells, each of which will develop into a zoospore.

large ovoid biciliate zoospore. In the spring frequently all the vegetative cells form zoospores simultaneously. The zoospore is provided with a chloroplast. It escapes through a pore in the wall of the mother cell and swims in water for some time; then it comes to rest and begins to divide to produce a new thallus.

Sexual Reproduction. Sexual reproduction is of advanced type and *oogamous*, the reproductive organs being differentiated into **antheridium** and **oogonium**, with motile antherozoid and non-motile egg respectively. The plant may be *homothallic* or *heterothallic*. Any vegetative cell may divide into a number of smaller cells, each cell being a male gametangium or antheridium (*C*), producing a single small motile biciliate antherozoid. In the formation of the oogonium (*D*) some of the marginal cells of the thallus enlarge and become oogonia. The protoplast of the oogonium is coverted into a large passive (nonmotile) egg. The remaining marginal cells not involved in the formation of the oogonia continue to grow so that the oogonia soon come to lie away from the margin.

In the filamentous species the antheridia and the oogonia are formed terminally at the ends of filaments, either by the same plant or by two different plants. In certain species the oogonium is provided with a beak-like projection, called the *trichogyne*, which receives the antherozoids and allows them to pass through it into the oogonium.

Fertilization. The antherozoids swim to the oogonium and one of them fuses with the egg-nucleus. After fertilization the egg clothes itself with a heavy wall which soon turns brown; this is the **zygote** (oospore; *E*). The adjoining vegetative cells of the thallus overgrow the zygote and completely enclose it. After a period of rest the zygote, still within the encased oogonium, divides and gives rise to 16 or 32 daughter cells, each of which is converted into a biciliate zoospore. The zygote wall and the encasing layer break and the zoospores are liberated. Each then directly develops into a new thallus.

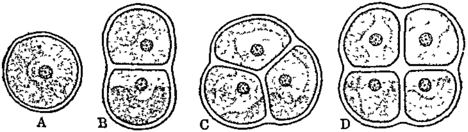
The zygote is diploid, but its first division being reductional all the zoospores formed as a result of successive divisions are haploid, and so also the plant body developed from each. Thus there is no alternation of generations in *Coleochaete*. Further it may be noted that the thalloid form of the plant body coupled with the advanced form of reproduction (oogamy) raises *Coleochaete* to a very high systematic position among the green algae—a near approach to thalloid liverworts.

8. *PROTOCOCCUS* (*14 sp.*)

Protococcus (or *Pleurococcus*; FIG. 19) is a very common unicellular green alga. It is terrestrial in habit and is very widely distributed. This alga grows in moist shady places and forms a green covering on tree-trunks, old damp bricks or brick walls, flower-pots and other similar objects. Each plant is represented by a single more or less globose cell, occurring either as isolated individuals or forming small groups (colonies) of 2, 3, 4 or more cells as a result of division of the solitary cell. Ciliate cells and gelatinous covering are conspicuous by their absence. Under conditions of excessive moisture and possibly under other conditions *Protococcus* may divide in one direction and

form short filaments consisting of a few cells, usually 3 or 4, sometimes many more.

Structure. Individual cells are very small and spherical or oval in shape, filled with *a dense cytoplasm and covered by a rather heavy* cellulose wall. A single nucleus is present in each cell, and there is a large parietal chloroplast with lobed margin but no pyrenoid.



Protococcus. FIG. 19. *A*, a single cell; *B-D*, small colonies formed by divisions of the cell.

Reproduction. The only method of reproduction is vegetative cell *division which is often very rapid. The first division of the cell is* transverse (median) and succeeding divisions, if any, are at right angles to the first one. The daughter cells may remain attached to one another in a small group or they may separate and form independent bodies. *Protococcus* cells have the remarkable power of resisting desiccation, and they begin to divide again under favourable conditions.

In the past *Protococcus* was regarded as one of the most primitive forms of green algae but now it is regarded as a reduced form of some filamentous type, possibly of Ulotrichales or Chaetophorales. The occasional branching, short and irregular though it is, lends support to this view.

9. *SPIROGYRA (100 sp.)*

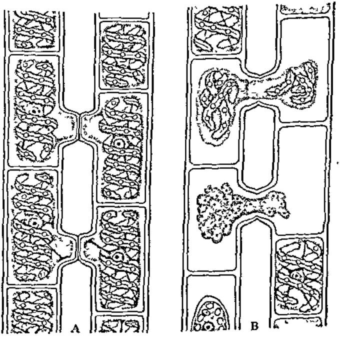
Occurrence. *Spirogyra* (FIG. 20) is a green filamentous alga, occurring in a tangled mass which is seen to float about freely in water. It is a cosmopolitan plant of fresh water, and is found growing abundantly in ponds, ditches, springs, slow-running streams, etc. In some species growing in running water a short unicellular organ of attachment called *haptera* is, however, formed.

Structure. Each *Spirogyra* plant is an unbranched filament, a few to many cm. in length, consisting of a single row of cylindrical cells. The walls are made of cellulose and pectin. Pectin swells in water into a gelatinous sheath, and the *Spirogyra* filament becomes invested by this sheath. It is, therefore, slimy to touch. The filament shows no differentiation into the base and the apex. Each cell has a lining layer of cytoplasm in which one or usually more *spiral bands* of

chloroplasts—the characteristic feature of *Spirogyra*—lie embedded. The nucleus is situated somewhere in the centre suspended by delicate strands of cytoplasm, and there is one large central vacuole. Chloroplasts vary in number from 1 to 14 in each cell, and run along the whole length of the cell. The margin of each chloroplast may be quite smooth or wavy or serrated. It includes in its body a number of nodular protoplasmic bodies, known as *pyrenoids*. Pyrenoids are connected by a sort of ridge which develops on the inner side of the chloroplast, and around them minute starch grains are deposited. There is usually one large nucleolus in each nucleus, but frequently more. Growth by elongation and cell division by mitosis usually take place at night. If the filament happens to be broken up into individual cells or into short pieces, the cells divide and give rise to new filaments (vegetative propagation).

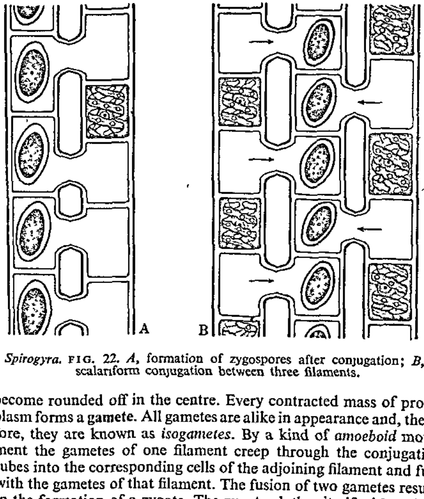
Spirogyra FIG. 20. A cell of the filament showing two spiral bands of chloroplasts with nodular pyrenoids, and a nucleus suspended by delicate strands of cytoplasm.

Reproduction. This takes place in *Spirogyra* by the sexual method, and consists in the fusion (conjugation) of two similar reproductive units or gametes, i e. isogametes. Conjugation usually takes place between the cells of two filaments or even three; this is called scalariform (or ladder-



Spirogyra. FIG. 21. Scalariform conjugation. *A-B* are stages in the process.

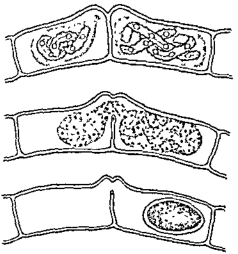
like) conjugation. Sometimes, however, conjugation takes place between the cells of the same filament; this is called lateral conjugation. **Scalariform conjugation** (FIG. 21). When two filaments come to lie in contact in the parallel direction they repel each other. As a result of this repulsion tubular outgrowths develop from the opposite or corresponding points of contact of the two filaments. These tubular outgrowths are called **conjugation tubes**, and when all or most of the cells of the two filaments have formed such tubes the whole structure looks more or less like a ladder and hence the name scalariform or ladder-like conjugation. Their end- or partition-walls dissolve and an open conjugation tube is formed. In the meantime the protoplasmic contents of each cell lose water, contract and



Spirogyra. FIG. 22. *A*, formation of zygospores after conjugation; *B*, scalariform conjugation between three filaments.

become rounded off in the centre. Every contracted mass of protoplasm forms a **gamete**. All gametes are alike in appearance and, therefore, they are known as *isogametes*. By a kind of *amoeboid* movement the gametes of one filament creep through the conjugation tubes into the corresponding cells of the adjoining filament and fuse with the gametes of that filament. The fusion of two gametes results in the formation of a zygote. The zygote clothes itself with a thick wall, and is known as the **zygospore** (FIG. 22A). In some cases the gametes may fuse in the conjugating tubes. The wall of the zygospore is thick and black or brownish-black. It is to be noted that the

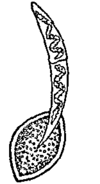
gametes of one filament always pass on to the gametes of the other filament. Thus one filament becomes practically empty except for a few vegetative cells here and there; while the other one is provided with a row of zygospores Sometimes it is seen that three filaments are involved in the process of conjugation, zygospores being formed in the middle filament (FIG. 22B). **Lateral conjugation** (FIG. 23). This takes place between the cells of the same filament. An outgrowth or conjugation tube is formed on one side of the partition wall, and through the passage, thus formed, the gamete of one cell passes into the neighbouring cell. Instead of a conjugation tube an opening may be formed in the partition wall through which the gamete may pass. In lateral conjugation the gametes of alternate cells only move to the neighbouring cells, and thus later on zygote-bearing cells are seen to alternate with empty cells in the same filament.



Spirogyra. FIG. 23. Lateral conjugation and formation of zygospore.

Sometimes it so happens that conjugation does not take place, and then the gametangia become converted into thick-walled bodies identical with zygospores; these bodies which are thus formed parthenogenetically (see p. 371) are called **azygospores** or **parthenospores**. They germinate like the zygospores.

Note. In *Spirogyra* there is no distinction between male and female gametes so far as their shape and structure are concerned, but there is some difference in their behaviour; one is active, motile and initiative and may be regarded as male; while the other is passive, non-motile and receptive and may be regarded as female. Normally all the cells of one filament behave as male, and those of the other as female. It is also seen that the chloroplasts of the male gamete become disorganized; while those of the female gamete persist as broken filaments.

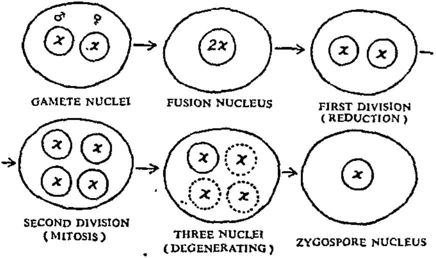


Spirogyra. FIG. 24. Zygospore germinating.

Germination of Zygospore (FIG. 24). The zygospore is provided with a thick cellulose-wall, composed of three layers, of which the middle one contains some chitin. It sinks to the bottom of the tank or the water in which it is growing. It undergoes a period of rest and then germinates. The protoplast of

he zygospore at first increases in size; then its outer walls burst and he inner wall with the protoplast grows out in the form of a hort tube which ultimately forms into a new filament. The filament scapes and floats on the surface of water. Cells divide and the ilament increases in length. (Life-cycle of *Spirogyra* is depicted in IG. 26.)

Reduction Division (FIG. 25). It is to be noted that the zygote is formed as a result f fusion of two gametes, each with n (or x) chromosomes and, therefore, the



Spirogyra. FIG. 25. Reduction division of zygospore-nucleus.

zygote nucleus has $2n$ (or $2x$) chromosomes. The nucleus of the zygote at first undergoes a reduction division, the resulting nuclei divide again so as to form four nuclei, each with n (or x) chromosomes. Three of these nuclei degenerate so that the mature zygote contains a single nucleus with n (or x) chromosomes.

10. *ZYGNEMA* (95 *sp.*)

Occurrence. *Zygnema* and *Spirogyra*, well-known members of *Zygnemataceae*, are widely distributed green algae occurring in almost every pool of fresh water and floating on it. Some species, however, produce rhizoid-like organs of attachment, called *haptera*.

Structure. Each plant of *Zygnema* (FIG. 27) is an unbranched filament without any differentiation between base and apex. The filament consists of a row of cylindrical cells. The protoplast of each cell is uninucleate, and the nucleus lies embedded in a broad strand of cytoplasm connecting two star-shaped chloroplasts which lie in the axial direction (*A*). Each chloroplast has delicate strands of cytoplasm radiating outwards, often to the wall. The stellate chloroplast is characteristic of *Zygnema*. A single large pyrenoid lies at the centre of each chloroplast and is surrounded by radiating starch grains. In the division of the cell the nucleus first undergoes mitosis and this

is followed by the furrowing of the cytoplasm in the middle of the cell. Each of the two chloroplasts, thus separated, divides and so

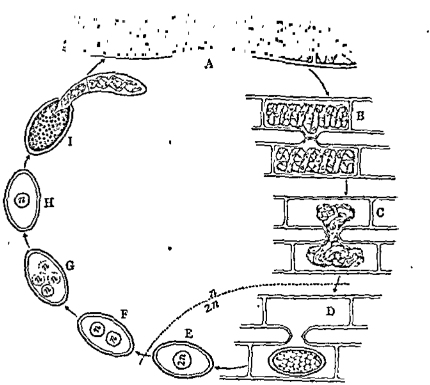


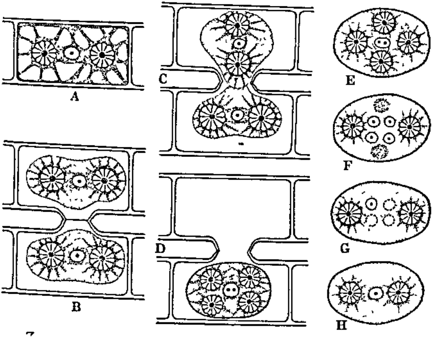
FIG 26. Life-cycle of *Spirogyra*. *A*, vegetative filament (portion); *B-C*, stages in conjugation; *D*, zygospore formed; *E-H*, reduction division and nuclear changes within the zygospore; and *I*, zygospore germinates

does the pyrenoid. The different organs then take their respective positions, as in the mother cell.

Reproduction. As in *Spirogyra*, reproduction in *Zygnema* takes place vegetatively and sexually. Both are conspicuous by the total absence of ciliate gametes or zoospores. **Vegetative reproduction** takes place only by the accidental breaking-off of the old filament into short fragments which grow by cell division and cell elongation.

Sexual Reproduction takes place by means of conjugation (*B-C*) usually in the spring. Both the methods of conjugation, viz., scalariform and lateral, are found in *Zygnema*, and show a marked similarity with those of *Spirogyra*. Scalariform conjugation is, however, the usual method. In some species the gametes (isogametes) of the conjugating filaments migrate from their respective gametangia, meet and fuse in pairs in the conjugation tube, and form the zygospore there; while in other species the gametes (aplanogametes) of one filament (male) move through the conjugation-tubes into the gametangia of the attached filament (female), and after gametic union the

zygospores develop in the latter (female) filament (*D*). The zygospore-nucleus has diploid chromosomes but on the eve of its germination it undergoes reduction division into four haploid nuclei. Three of them, however, degenerate. The zygospore has at first four chloroplasts but soon two of them degenerate (*E-H*). There are three walls covering the zygospore. The latter germinates only the year after by producing a short filament which escapes from the zygospore. It divides and elongates into a mature filament.



Sometimes when conjugation fails the gametes may be converted into azygospores or parthenospores which are essentially identical with the zygospores. Azygospores are rather common in some species of *Zygnema*.

11. *COSMARIUM* (*over 800 sp.*)

The genus *Cosmarium* is a member of the family *Desmidiaceae*, commonly called desmids. Desmids are a big group of unicellular plants comprising about 2,500 species. They have a variety of peculiar, often exceedingly beautiful, forms (FIG. 28), and are very widely distributed; they are found abundantly in almost every pool of fresh water. Sometimes the cells are held together in an unbranched filament or in an amorphous colony. Many of the desmids show a jerky

movement which is due to the secretion of mucilage through the pores in the cell-wall. *Cosmarium* like other desmids is a freshwater, free-floating alga.

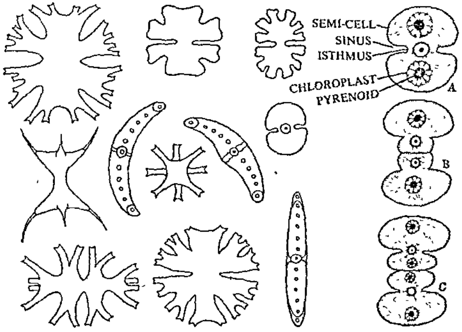


FIG. 28 FIG. 29A

Desmids. FIG. 28. Various forms of desmids including *Cosmarium*. FIG. 29A. *Cosmarium*. *A*, a vegetative cell; *B-C*, mode of vegetative reproduction.

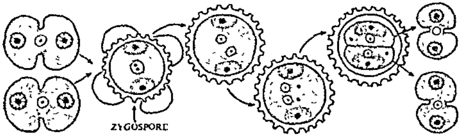
Structure. The body of *Cosmarium* (FIG. 29A) is represented by a single cell (*A*) with a median constriction, called *sinus*, which divides the cell into two distinct symmetrical halves (*semicells*) connected by a narrow zone, called *isthmus*. The cell-wall is smooth and consists of three concentric layers—(*a*) an innermost thin layer made of cellulose, (*b*) a somewhat thicker median layer made of cellulose and pectic compounds, and (*c*) an outermost layer of gelatinous sheath. The two inner walls are provided with pores. The protoplast contains a single nucleus which lies at the isthmus, and commonly a single chloroplast with 1 or 2 pyrenoids in each semicell; 2-4 chloroplasts, sometimes many, are not, however, uncommon. A large chloroplast has often many pyrenoids.

Reproduction. *Cosmarium* reproduces vegetatively and sexually.

Vegetative Reproduction. During vegetative reproduction which is a process of cell division the nucleus of each cell divides into two and the isthmus elongates (*B-C*). A partition wall is formed across the isthmus. Each elongated portion of the isthmus then enlarges and gives rise to a new semicell. The chloroplast also divides. The pyre-

noids may divide or may be newly formed. The daughter cells separate, and thus two *Cosmarium* cells are formed. It is evident that each of the two newly formed semicells is always younger than the one belonging to the parent cell. No zoospore is formed in desmids.

Sexual Reproduction. Sexual reproduction, rare though it is, is isogamous. During conjugation (FIG. 29B) two mature cells or sometimes two newly formed daughter cells come in contact and are invested by a common gelatinous sheath. The protoplast of each cell



Cosmarium. FIG. 29B. Sexual reproduction (conjugation), zygospore and mode of its germination.

forms a gamete. Each cell then breaks open at the isthmus and the two gametes escape and meet midway between the two. In some species a distinct conjugation tube may be formed. In such cases the zygote is formed in the conjugation tube. The two gametes fuse forming a zygote. The zygote becomes thick-walled and spiny or warty, and remains enveloped by a gelatinous sheath, with the four empty semicells often adhering to it. It germinates after a period of rest and gives rise to two daughter protoplasts, each of which develops into a new *Cosmarium* plant. The zygote nucleus undergoes reduction division, with two haploid nuclei passing into each daughter protoplast. One nucleus in each degenerates and some of the chloroplasts except for the specific number also distintegrate. Thus a *Cosmarium* cell has only one nucleus, and one or two chloroplasts. The two newly formed *Cosmarium* cells escape by the rupture of the zygote wall.

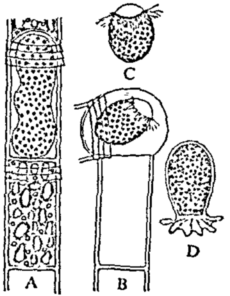
12. *OEDOGONIUM* (*300 sp.*)

Structure. *Oedogonium* (FIG. 30A) is a common green filamentous alga living in fresh water. Each plant is an unbranched filament consisting of a row of elongated cells. Filaments usually remain attached to any object by an irregularly lobed basal cell called the *holdfast*. Older filaments may float freely on water. The apex of the filament may be rounded or may end in a hair-like structure. Growth takes place by cell division and may be apical or intercalary. The cell-wall is somewhat thick and rigid consisting of cellulose internally, pectose in the middle and chitin externally. Ring-like markings, called apical

caps, are formed at the distal ends of some of the cells of the filament. Each cell contains a single nucleus and a single large peripheral chloroplast which takes the form of a network lining the cell-wall. Pyrenoids are present, each surrounded by a sheath of starch plates.

Reproduction takes place asexually by large solitary zoospores, and sexually by highly differentiated male and female gametes.

Asexual Reproduction (FIG. 30). This method of reproduction takes place by zoospore. Any cell of the filament may form a single zoospore by the process of rejuvenescence (see p. 343). The contents of



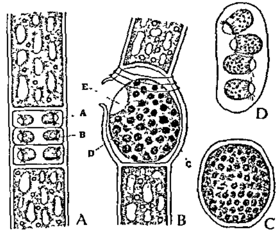
Oedogonium. Asexual Reproduction.
FIG. 30.
A, portion of a filament showing a chloroplast and a zoospore in the process of formation; B, zoospore escaping; C, zoospore swimming; D, zoospore attached to an object.

the cell become rounded off and form a zoospore. This is a large pear-shaped body. Its narrower end is clear and bears a ring of cilia; while its broader end is green containing a chloroplast. The zoospore escapes by transverse splitting of the upper wall of the cell, swims in water for a while and then gets attached to some object. All the cilia are withdrawn; it then clothes itself with a cell-wall and eventually germinates into a filament.

Sexual Reproduction (FIG. 31). Sexual reproduction takes place by differentiated male and female gametes, known respectively as antherozoid and oosphere or egg-cell. Many species are monoecious (*homothallic*), and some dioecious (*heterothallic*). Antherozoids are borne in certain small cells, known as antheridia (FIG. 31A). Antheridia are produced in a series by repeated divisions of any cell of the filament. The protoplasmic contents of each antheridium divide once and produce a pair of antherozoids. Each antherozoid is furnished with a ring of cilia and is like the zoospore, excepting that it is smaller in size. Antherozoids are liberated by a transverse slit of the antheridial wall.

The egg-cell is borne in a large spherical cell known as the **oogonium** (FIG. 31B). Oogonia occur amongst the ordinary vegetative cells of

Oedogonium.
Sexual Reproduction.
FIG. 31.
A, portion of a filament showing antheridia (*A*) and antherozoids (*B*),
B, a filament showing oogonium (*C*) and egg-cell (*D*) with receptive spot (*E*);
C, an oospore;
D, formation of zoospores from it.

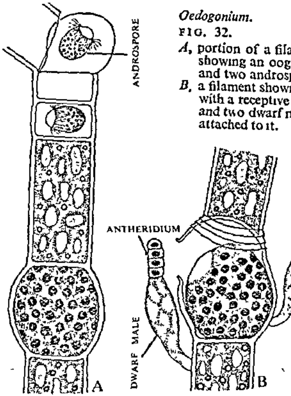


the filament, either singly or 2 or more in a row. The protoplasmic contents of the oogonium separate from the cell-wall and become rounded off, forming a single, large, nonmotile egg-cell or oosphere. This egg-cell enlarges and becomes spherical or oval. There is a colourless receptive spot at one end of it, and close to this spot the oogonium opens by a pore or a transverse slit of the wall.

Fertilization. When the antherozoids are liberated they swim to the oogonium with the help of their cilia. Then one antherozoid enters through the slit in the oogonium wall and fuses with the egg-nucleus at the receptive spot (FIG. 31B). The oosphere then covers itself with a thick cell-wall and becomes a reddish-brown **oospore** (FIG. 31C): The oospore sinks to the bottom, undergoes a period of rest and then germinates. The nucleus of the oospore has $2n$ chromosomes. It undergoes reduction division giving rise to four **zoospores** (FIG. 31D), each with n chromosomes. The zoospores escape and swim about for some time. Then they rest for a while, attach themselves to some object, and each germinates into a new filament.

In some species of *Oedogonium* a complicated process of reproduction takes place. In them a special type of zoospore, called **androspore** (FIG. 32A), is produced by the same filament that bears the oogonia or by a distinct filament. Androspores are produced in special cells, called **androsporangia**, which are formed either singly or in a row like the antheridia by division of the ordinary vegetative cells of the filament. Each androsporangium produces a single androspore which like the antherozoid is provided with a crown of cilia and is motile. The androspore is intermediate in size between the zoospore and the antherozoid. When liberated, the androspore swims for a while and soon attaches itself direct to the oogonium or to a cell close to it. It then produces a short narrow filament, called

dwarf male (FIG. 32B), consisting of an elongated basal cell and a terminal cell or sometimes a row of cells (usually 2 to 4). Each such cell is an antheridium. It bears a pair of small motile antherozoids



Oedogonium.
FIG. 32.
A, portion of a filament showing an oogonium and two androspores;
B, a filament showing oogonium with a receptive spot and two dwarf males attached to it.

crowned with cilia. The antheridium opens by a lid at the apex or it ruptures by the wall and the antherozoids are liberated. They swim to the oogonium and fertilization takes place in the usual way.

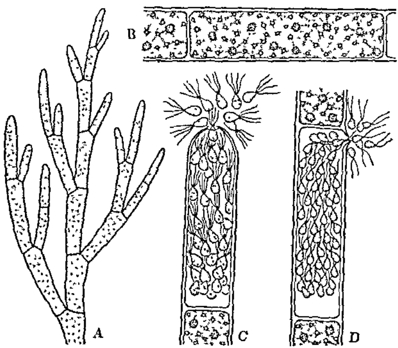
13. *CLADOPHORA (160 sp.)*

Occurrence. *Cladophora* (FIG. 33) is a very widely distributed genus commonly found in freshwater ponds, lakes and streams, growing there attached to some objects by rhizoid-like branches. A few species are marine.

Structure. The plant body consists of freely branched filaments. Each filament is made of a row of cylindrical cells united end to end (*A-B*). The branching is lateral although sometimes it looks dichotomous. The cells are coenocytic in nature containing numerous nuclei. The chloroplast is parietal encircling the cytoplasm and is reticulate enclosing many pyrenoids. There is a large central vacuole. The cell-wall is made of three layers—the outer composed of chitin, the middle of pectic compounds and the inner of cellulose.

Reproduction. Vegetative reproduction takes place by certain cells, lying at the base of the plant, filled with a heavy store of food. After the filaments die back such cells grow up into new filaments in the following season. Asexual reproduction takes place by quadriciliate zoospores (*C*) which are formed in large

numbers in the apical cell and in other cells close to it (asexual plant). The zoospores are uninucleate. They escape one by one through a minute pore formed at or near the upper end of the cell-wall. After swarming for a while each secretes a wall, quickly elongates and develops into a new plant (sexual plant). Sexual reproduction takes place by isogametes borne by the sexual plant only in any of its vegetative cells. The gametes are biciliate (*D*), and are produced in large numbers like the zoospores. Gametes borne by two different plants fuse in pairs,



gametangium.

Cladophora being *heterothallic*. The zygote formed as a result of fusion grows within a day or two directly into a new plant (asexual plant). It reproduces by zoospores again. It will be noted that the spore- (zoospore-) bearing plant, i.e. the asexual plant, is diploid, and the gamete-bearing plant, i.e. the sexual plant, is haploid, but both are alike in appearance. Reduction division takes place in the formation of zoospores. *Cladophora* shows *isomorphic* alternation of generations. Stages in the life-history are shown below:

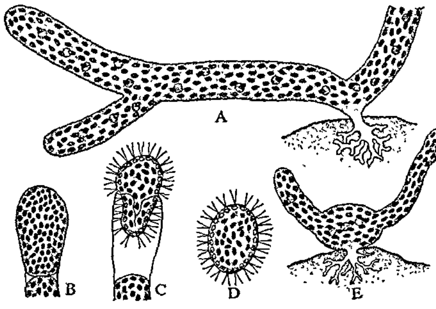
1 Asexual plant ($2n$)⟶zoospores (n)⟶sexual plant (n).
2 Sexual plant (n)⟶isogametes (n)⟶zygote ($2n$)⟶asexual plant ($2n$).
(fusion in pairs)

14. *VAUCHERIA* (*35 sp.*)

Occurrence. *Vaucheria* (FIG. 34A) is a green alga of fresh water, growing with other algae in ponds, ditches and also in the wet soil. It is

not free-floating like *Spirogyra* but is mostly attached to a substratum by means of colourless rhizoids or holdfasts. It is deep-green in colour and always lives in a tangled mass.

Structure. The thallus consists of a single branched tubular filament. It is unseptate, and contains numerous minute nuclei which lie embedded in the lining layer of cytoplasm. Such a structure is known as a coenocyte. *Vaucheria* is, therefore, a coenocyte. There is a large central vacuole which runs the whole length of the coenocyte. Septa,



Vaucheria. FIG. 34. *A*, a *Vaucheria* filament; *B*, formation of zoosporangium; *C*, zoospore escaping; *D*, free-swimming zoospore; *E*, zoospore germinating.

however, normally appear in connexion with the reproductive organs. Injury also results in the production of septa cutting off the injured parts which then develop into new plants. Filaments increase in length by apical growth. Chloroplasts are numerous, very small and discoidal in shape. They lie embedded in the lining layer of cytoplasm, and are without pyrenoids. Protoplasm contains abundant oil-globules, but lacks in starch.

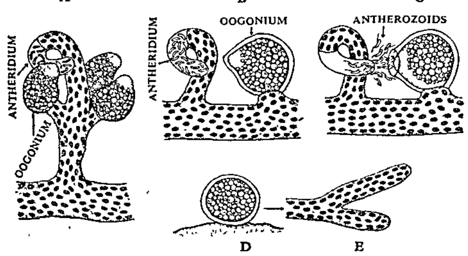
Reproduction. This takes place asexually as well as sexually.

Asexual Reproduction. [illegible] spore. During its develop[illegible] becomes club-shaped and [illegible] ment by a septum. This club-shaped body is known as the **zoosporangium** (FIG. 34B). Its protoplasmic contents become rounded off, forming a single **zoospore**. The wall of the zoosporangium rup-

tures at the apex, and the zoospore escapes through the apical pore (FIG. 34C) and begins to rotate. The zoospore (FIG. 34D) is an oval body of large size. The central part of it is occupied by a large vacuole, and in the surrounding zone of the cytoplasm there lie embedded numerous small chloroplasts, giving the zoospore an intensely deep-green colour. The whole surface of the naked (without cell-wall) zoospore is covered with numerous short cilia arranged in pairs; under each pair of cilia there lies a nucleus. For this reason the zoospore is regarded as a compound one. The zoospores generally escape in the morning. They swim about freely in water for a while (half an hour or less) by the vibration of their cilia and soon come to rest. The cilia are immediately withdrawn and a cell-wall is developed round them. After coming to rest the zoospores germinate (FIG. 34E) almost immediately by the protrusion of one or more tube-like filaments, one of which, at least, produces a colourless branched rhizoid, and attaches the plant to the substratum. The protoplasm leaves the old cell and rejuvenates, i.e. it becomes young and active; this method of asexual reproduction is known as **rejuvenescence.**

Sexual Reproduction. This takes place by the method of **fertilization,** that is, by sharply differentiated male and female organs. Male organs are known as **antheridia** and female organs as **oogonia** and these are developed at scattered intervals as lateral outgrowths. Antheridia and oogonia commonly arise side by side on the same vegetative filament (FIG. 35 B-C) or on short lateral branches of it (FIG. 35A).

The outgrowth that forms the **oogonium** swells out, assumes a



more or less rounded form, and is cut off by a basal septum (FIG. 35 A-C). The apex of the oogonium generally develops a *beak*, either towards the antheridium or away from it. The protoplasm of the oogonium contains much oil, numerous chloroplasts, but only one nucleus. There is a single large egg-cell or oosphere which completely fills the oogonium. The oogonium is at first multinucleate, but before the partition wall is formed all the nuclei except one (the egg-nucleus) return to the main filament or they degenerate.

Each **antheridium** arises as a short tubular branch by the side of the oogonium, and simultaneously with it. Its terminal portion is cut off by a septum, and it then becomes the actual antheridium (FIG. 35 A-C). As it matures it usually becomes much curved towards the oogonium. The protoplasm contains numerous chloroplasts and nuclei. Numerous male gametes, known as **antherozoids**, are produced inside each antheridium. They are very minute in size and are biciliate. The cilia point in opposite directions.

Fertilization. The antheridium bursts at the apex and the antherozoids swarm in the vicinity of the oogonium, the beak of which opens at the same time (FIG. 35C). Only one antherozoid enters through the beak and fuses with the egg-nucleus, while the rest perish. Thus fertilization is effected. *Vaucheria* is homothallic, and self-fertilization is the general rule. After fertilization the oosphere becomes invested with a thick cell wall, and is known as the **oospore** (FIG. 35D). The oospore undergoes a period of rest and then it germinates directly into a new *Vaucheria* filament (FIG. 35E). Reduction division has not yet been observed in *Vaucheria*.

15. *CAULERPA* (*60 sp.*)

Occurrence. All the species of *Caulerpa* are marine growing in shallow or deep water in tropical seas. They grow attached to the mud- or sand-bottom, rock, coral-reef or to the roots of mangrove plants.

Structure. The plant body is represented by a single-celled thallus with a slender creeping rhizome which bears colourless root-like rhizoids on its lower surface, and erect leafy shoots on the upper surface. The plant body is a branched coenocyte (unicellular without any partition wall but multinucleate), usually 10-30 cm. in height. The cell-wall made of callose and pectic substances is comparatively thick with many ingrowths in the form of transverse and longitudinal rods, called the *trabeculae*, which give rigidity to the thallus to some extent. The cytoplasm forms a lining layer within the cell-wall and contains numerous nuclei and disc-shaped chloroplasts, the latter, however, without any pyrenoid. There is a large vacuole at the centre running lengthwise through the entire body of the plant.

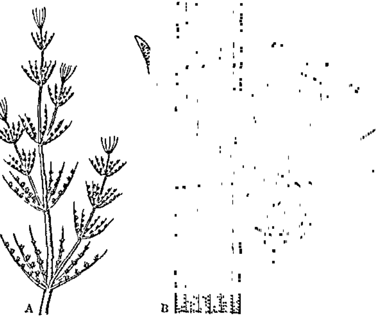
Reproduction. Vegetative reproduction is effected by fragmentation of the thallus into several parts or by detachment of the leafy shoot from the rhizome. Asexual and sexual reproduction is only imperfectly known. Asexual reproduction takes

place by means of zoospores. These are generally produced from any portion of the leafy shoot or sometimes from the rhizome. Numerous papilla-like outgrowths called the *extrusion papillae* develop on the surface of the thallus and through them zoospores are liberated, sometimes in a large quantity like a mass of fine particles. The zoospores are pear-shaped and biciliate. Each is provided with a single chloroplast without pyrenoid, and an eye spot. Sexual reproduction has not been observed in all species. In *Caulerpa clavifera* and some other species the mode of reproduction is *anisogamous* and the plants are dioecious (heterothallic). Gametes formed in the erect leafy shoot are biciliate Female gametes are somewhat longer and broader than the male gametes, As the zygote matures the thallus disintegrates. But the germination of the zygote has not been observed.

CLASS IV | CHAROPHYCEAE | or stoneworts 215 sp.

CHARA (*90 sp.*)

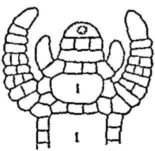
Occurrence. *Chara* (FIG. 36A), a common stonewort, grows submerged in fresh water of ponds, lakes, streams and other pools of standing water, remaining attached to the bottom by branched filamentous rhizoids. Some species grow in brackish water. The body



Chara. FIG. 36. *A*, a plant (upper portion) showing long and short branches; *B*, a branch showing an oogonium with sterile jacket and crown, and an antheridium covered by shield cells.

is often encrusted with lime which sometimes forms a thick deposit at the bottom. *Chara* and *Nitella*-are two very common genera of *Characeae*.

Structure. The plant body consists of an erect branched stem, usually 20-30 cm. in height, differentiated into distinct nodes and internodes. Branching is of the following types: (*a*) at each node of the stem and the long branches there is a whorl of short branches (of limited growth) consisting usually of 3-8 nodes and internodes; (*b*) long slender branches (of unlimited growth) bearing again short branches; and (*c*) still shorter branches (leaves) of one internode borne by the long and short branches at their nodes together with the complex sexual organs (FIG. 36B). The internode consists of a single large cylindrical cell ensheathed by a layer of narrow vertical cells forming the cortex. The cortical cells arise partly from the upper node and partly from the lower node and meet somewhere in the middle of the internode. Growth in length of the stem takes place by a *dome-shaped* apical cell (FIG. 37). All the cells contain numerous small chloroplasts but no pyrenoids, and the reserve food occurs in the form of starch. The rotatory movement of the protoplasm round a large central vacuole is very conspicuous in the internodal cells.



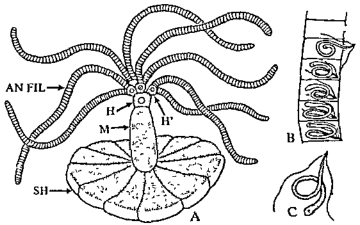
Chara. FIG. 37. Growing apical cell, nodes and internodes (*I*) in stem-apex.

Reproduction. The plant normally reproduces sexually and sometimes vegetatively. Asexual reproduction is not known. Vegetative reproduction may take place by tuber-like outgrowths or by protonemal filaments developing from the nodes or sometimes from the rhizoids.

Sexual Reproduction. All species of *Chara* normally reproduce sexually. The male and the female fructifications, respectively called **antheridium** (otherwise called *globule*) and **oogonium** (otherwise called *nucule*), are very complex structures with enveloping sheath. These are borne at the nodes of short branches together with the still shorter unicellular branches (FIG. 36B), and are visible to the naked eye. Most species of *Chara* are *homothallic* (monoecious) and in them the antheridium and the oogonium always occur in pairs, with the latter lying just above the former.

The **antheridium** (FIG. 38A) is a very complex body. It is spherical in shape and turns red or orange when mature. Its wall is made of eight curved plate-like cells, somewhat triangular in shape, called **shields**, with peculiar thickening on the surface and their walls folded and fitting into one another. From the centre of each shield a cylindrical cell called the **manubrium** or handle cell projects inwards. The manubrium terminates inwardly in a roundish cell, called the *primary capitulum* or primary head cell. Each head cell cuts off still

smaller cells known as the *secondary capitula* or secondary head cells. Each of these cells produces a pair of longer slender **antheridial filaments** (FIG. 38A-B), each consisting of 100-200 tiny cells, called **antheridial cells.** The antheridial filaments form a tangled mass in the cavity of the antheridium. The protoplast of an antheridial cell forms a single, coiled, biciliate **antherozoid** (FIG. 38B-C). There may be as



many as 20,000-50,000 antherozoids produced by a single antheridium. Besides, there is an elongated stalk cell, called the **pedicel cell,** projecting into the cavity of the antheridium.

The **oogonium** is an ovoid structure and much bigger than the antheridium. Closely encircling the oogonium there are five spiral bands of cells, called **jacket cells.** These cells arise at the base and after completely surrounding the oogonium cut off at their tips five small cells which form the **crown** or **corona.** The oogonium contains a single large uninucleate egg and plenty of food material.

Fertilization. When the antheridium matures it gets ruptured at the junctions of shield cells and the antheridial filaments become exposed. The antherozoids escape through slits or pores in the walls of the antheridial cells and swim about in water. The crown cells of the oogonium slightly separate at their base leaving five small slits through which the antherozoids enter. Finally one of them fuses with the egg-nucleus and thus fertilization is effected. The zygote (oospore) clothes itself with a thick wall, and the oogonium as a whole hardens. The zygote germinates after a period of rest. The zygote nucleus undergoes reduction division forming four haploid

nuclei, three of which degenerate. On germination the zygote gives rise to a rhizoid and a green filament (protonema); the shoot of the *Chara* plant arises from the protonema as a lateral bud

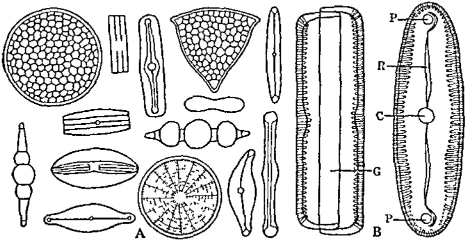
Origin and Relationship of *Characeae* *Characeae* or stoneworts hold a unique position among the green thallophytes. They are possibly related to Chlorophyceae but the degree of relationship cannot be ascertained *Characeae* is an ancient group and may have arisen as an offshoot from some early Chlorophyceae. Their bright green colour and storage of carbohydrate in the form of starch indicate some relationship with the green algae. But the erect vegetative body with nodes and internodes, and the complex reproductive organs with sterile sheath are distinctive features. The multicellular sex organs tend to raise this group to a higher level (bryophytic level), but the structure and development of these organs are very different in the two groups, and the sporophytic phase, so well developed in stages in bryophyta, is absent in *Characeae*. For the present, therefore, *Characeae* may be treated as a distinct and isolated class (Charophyceae) of green thallophytes.

CLASS V | BACILLARIOPHYCEAE or diatoms | 5,300 sp.

General Description. Bacillariophyceae, commonly called **diatoms**, constitute a big isolated group of mostly one-celled algae which are of infinite varieties of forms and often of exquisite beauty; the single cells may occasionally form filaments and colonies. They are universally distributed in fresh water as well as in salt water and also in wet ground. In some parts of the ocean they occur in a vast assemblage as floating *plankton*. Sometimes they occur in huge numbers in a small space. Diatoms are mostly free-floating, while some remain attached by a gelatinous stalk. Many of the free-floating diatoms exhibit a jerky movement visible under a microscope. There are over 5,300 living species of diatoms. Fossil diatoms are seen to have formed huge deposits of siliceous or diatomaceous earth, often of considerable depth, in various parts of the world.

Structure. Diatoms (FIG. 39) may be boat-shaped, rod-shaped, disc-shaped, wedge-shaped, spindle-shaped, circular, oval, rectangular, etc. The wall of the diatom cell is made of two halves or valves, one (older) fitting closely over the other (younger) very much like a pill-box or soap-case, the outer valve being known as the *epitheca* and the inner one as the *hypotheca*. The valves are made of pectin impregnated with silica. The valves are ornamented with numerous fine lines which are really series of very fine *dots*. The ornamentation which is a special feature of diatom valves is radially symmetrical in the round or centric diatoms (called Centrales), so frequent in the ocean, and it is bilaterally symmetrical (in two series, one on each side of the valve) in the elongated or pinnate diatoms (called Pennales), so frequent in the fresh water. In some genera there are

ingrowths of the wall, which according to their position, are called central nodules or polar nodules. Extending from the central to the polar nodule there is in many diatoms a longitudinal line or slit consisting really of a series of extremely minute openings; this line is called *raphe*. The jerky movement seen only in those diatoms which



Diatoms FIG. 39. *A*, various forms of diatoms; *B*, a diatom (*Pinnularia*); *left*, girdle view showing overlapping valves; *right*, valve view showing raphe; *G*, girdle; *P*, polar nodule; *R*, raphe; *C*, central nodule.

possess a raphe may be due to the streaming movement of the cytoplasm along the raphe thrusting psuedopodia through the openings of it (raphe) and setting up a water current. Under the microscope commonly either the *valve side* is seen, i.e. the valve is uppermost, or the *girdle side* is seen, i.e. the connecting band is uppermost.

. The protoplast consists of a thin peripheral layer of cytoplasm just within the cell-wall, one large or many small yellow to golden brown plastids of varied shape and size, a central nucleus suspended by a distinct transverse cytoplasmic thread, and a vacuole. The colour is due to the presence of a golden-brown pigment called *diatomin* in addition to chlorophyll. Pyrenoids may or may not be present. If present, they are without the starchy envelope. The reserve foods are globules of fats and globules of an insoluble complex substance called *volutin*. No starch is formed in diatoms.

Reproduction. Diatoms may reproduce *vegetatively* by cell division generally at night, *asexually* by auxospore, and *sexually* by conjugation of gametes; but all these methods are *unique*. Vegetatively the protoplast grows and divides into two, resulting in the separation of the two valves. Each of the two half-cells forms a new valve against the old one fitting into it. Divisions and valve-formations continue one after the other. The result, as is evident, is that by this method one set of cells gradually become smaller and smaller. The

reduction in size is not, however, true of all forms. It is seen that when a particular minimum size is reached, a reversion to original size takes place through the formation and activity of a special kind of cell called auxospore. The auxospore may be formed in a variety of ways. (1) In the first method the protoplast of a cell may escape from the valves after separation of the latter; it grows to its maximum size and then forms new valves. The protoplast acts as an auxospore. (2) In the second method the protoplast divides into two, each daughter protoplast (an auxospore) growing and forming new valves. (3) In the third method which is a sexual one the protoplasts of two cells escape and act as two gametes; they fuse to produce a zygote which behaves as an auxospore. (4) In the fourth method two contiguous diatom cells form two gametes each; they fuse in pairs forming two zygotes which act as auxospores. The auxospore grows and helps the diatom to return to its original size.

Diatomaceous earth has a variety of uses. It is used in metal polish, toothpaste, paints and plastics. It is extensively used as a filter in filtration of liquids, e.g. sugar refining. It is also used as a heat-insulator in boilers and furnaces which can then stand very high temperature.

CLASS VI | PHAEOPHYCEAE or brown algae | 1,000 sp.

General Characters. Phaeophyceae or brown algae are a very interesting group of seaweeds with a variety of peculiar forms and sizes, and comprise about 1,000 species. They are widely distributed along sea coasts between tidal levels, predominantly along the coasts of temperate seas, and grow attached to rocks or some other substratum; in colder seas they seldom go beyond a depth of 20 m., while in warmer seas a few species may grow to the maximum depth of 90 m.; some also grow as epiphytes or endophytes on other algae; a few are free-floating. Their colour ranges from brown to olive-green due to the presence of a brown pigment *fucoxanthin* which is associated with the chloroplasts masking the chlorophyll. Pyrenoids are absent. The reserve food may be a kind of sugar (and not starch) or more commonly a complex carbohydrate called *laminarin*. Some like *Ectocarpus* are short filaments; some like *Fucus* and *Sargassum* are usually a few cm. to 1 m. in length; while some are massive seaweeds, called giant kelps (*Laminaria*—2-9 m.; *Nereocystis*—45 m.; and *Macrocystis*—60-90 m.); they grow at or below the low tide level, extending far into the sea to a depth of about 90 m.; small kelps are only about a metre in length; unicellular brown algae are not known. The body of the kelp is differentiated into a basal root-like branched holdfast, a long or short stem called stipe, and one or

more leaf-like blades called **fronds** which are provided with air-bladders for facility of floating. Fronds are of massive sizes in some species. Phaeophyceae (except *Fucus* and *Sargassum*) show a regular alternation of generations with different degrees of development of the sporophyte and the gametophyte, the two being similar (isomorphic, as in *Ectocarpus*) or dissimilar (heteromorphic, as in *Laminaria*) in external appearance, and their motile cells (zoospores and gametes or sperms) are laterally biciliate, the two cilia being of unequal lengths, in contrast with the apically ciliate cells of most algae.

Reproduction. Motile reproductive bodies (zoospores and gametes or sperms) are universally present throughout Phaeophyceae. Several species reproduce vegetatively by fragmentation of the thallus; most of them reproduce asexually by zoospores or aplanospores (except *Fucus* and *Sargassum*). and sexually by isogamy, anisogamy or oogamy. The zygote germinates without any period of rest.

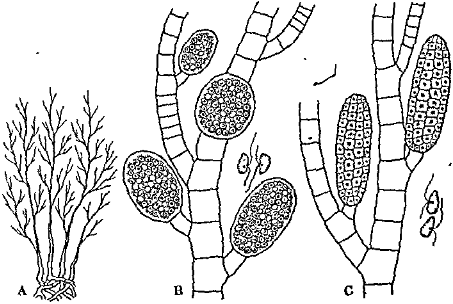
Uses. Kelps are sources of iodine. Many of them are rich in potassium and other minerals, and are used as fertilizers along coastal areas. They contain sugar and many are rich in vitamins. Some are eaten as food by the coastal people of China and Japan. Most of the brown algae form an important food for fishes. Algin, another product obtained from kelps (particularly *Laminaria* and *Macrocystis*), is used in certain industries, as in the making of ice cream, in the rubber industry, baking industry, paint industry and in certain pharmaceutical preparations.

Origin and Relationship of Phaeophyceae. Phaeophyceae or brown algae are supposed to have originated from some brown ciliate unicellular ancestor. The universal presence of motile ciliate reproductive cells lends support to this view. The brown algae do not seem to be related to the green algae. Their vegetative body (thallus) is always multicellular as opposed to many unicellular green algae. Then again the presence of fucoxanthin and the formation of laminarin are exclusive to this group. But because of the missing links their origin and relationship with other algae cannot be traced. Like green algae, however, they show progressive stages of sexual reproduction—isogamy to anisogamy to oogamy. Phaeophyceae have remained confined to the sea and have not given rise to land forms. Within the group, however, there seem to be two divergent lines of evolution—in one, the two alternating generations (sporophyte and gametophyte) are similar in external appearance; while in the other, the two generations are dissimilar. The origin of Fucales and their relationship with other brown algae are further shrouded in mystery.

1. *ECTOCARPUS*

Occurrence. *Ectocarpus*, a genus of *Ectocarpaceae*, is a simple brown alga. It is very widely distributed and found in plenty growing attached to other bigger algae or to rocks along the coasts of almost all seas.

Structure. *Ectocarpus* (FIG. 40A) occurs as tufts of branched filaments. Each filament is monosiphonous, i.e. it consists of a single row of cells. The plant body is differentiated into two portions: a prostrate portion and an erect portion. The cells are uninucleate with a few band-shaped or many small disc-shaped brown plastids (chromatophores). Although all individual plants of a species look alike vegetatively investigations have shown that there are actually two different kinds—one kind (asexual plant) is the sporophyte with diploid ($2n$ chromosomes) and the other kind (sexual plant) is the gametophyte with haploid (n chromosomes).

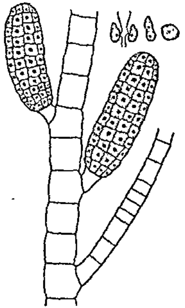


shown separately.

Reproduction. The sporophytic (diploid) plant reproduces asexually by two kinds of zoospores: one kind formed in a unilocular zoosporangium is haploid (FIG. 40B), and the other kind borne in a plurilocular zoosporangium is diploid (FIG. 40C). The gametophytic plant on the other hand, though very much like a sporophyte and hardly distinguishable from it, reproduces by gametes borne in *plurilocular gametangia*. The gametangia with gametes and the plurilocular zoosporangium with zoospores being alike, a good deal of confusion arose as to whether the structure concerned is really a gametangium or a sporangium. Investigations on cytology and behaviour of such reproductive bodies clarified the position. It was found that such zoospores are diploid and each grows by itself;

whereas the gametes are haploid and they fuse in pairs. Therefore the zoospore-bearing organ is the sporangium and the gamete-bearing organ is the gametangium, and the corresponding plants, though alike, are sporophyte and gametophyte respectively.

Asexual Reproduction. Cytologically there are two kinds of zoospores (borne by the sporophytic or asexual plant)—some haploid (with n chromosomes) and some diploid (with $2n$ chromosomes) borne respectively in a unilocular sporangium and a plurilocular sporangium. Both kinds of sporangia may be borne by the same plant or by two different plants. The unilocular sporangium may be a cell of the filament flattened to form it or it may develop at the end of a short lateral branch. In any case it bears 32 or 64 zoospores which, as said above, are haploid. These finally escape from the sporangium through a terminal opening and give rise to the gametophytes. The plurilocular sporangium on the other hand, borne likewise laterally, consists of several hundreds of small cells arranged in several (20-40) transverse tiers. Each cell of the sporangium develops a single zoospore. In both the cases the zoospores are laterally biciliate, with the cilia of different lengths. The zoospores of the plurilocular sporangium are diploid and on germination each zoospore gives rise to the diploid sporophyte again bearing plurilocular sporangium. *Ectocarpus* may indefinitely multiply by this method. Sometimes, depending on seasonal changes, the diploid zoospores borne in plurilocular sporangium develop plants which bear unilocular sporangia, with haploid zoospores. In this case reduction division takes place at an early stage of sporangium formation. Such zoospores grow into gametophytic plants.



Ectocarpus. FIG. 41. Sexual plant (n) with plurilocular gametangia; two gametes (n), conjugation, and zygote ($2n$) shown separately.

Sexual Reproduction. The gametophytic or sexual plant (FIG. 41) is like the sporophyte in appearance, and produces laterally long multicellular gametangia resembling plurilocular sporangia. Each cell of the gametangium produces a single laterally biciliate gamete. All gametes are alike in size (isogametes) but there is some difference in the behaviour (activity) of the pairing gametes. Gametes coming from different plants fuse in pairs, *Ectocarpus* being heterothallic. The gametes escape from the gametangium and swim in

water. A particular gamete (female) soon comes to rest, and one of the many active gametes (male) which cluster round it, fuses with it. The zygote that is formed is diploid and it grows without any period of rest into a sporophyte bearing unilocular or plurilocular sporangia or both, as described above. Sometimes some of the gametes, particularly the female ones, develop by parthenogenesis, i.e. without fertilization, into new haploid plants (gametophytes). The gametes thus behave as haploid zoospores.

Alternation of Generations. *Ectocarpus* shows *isomorphic* alternation of generations. The two generations are more or less equally developed. The spore- (zoospore-) bearing plant is the sporophyte (diploid), while the gamete-bearing plant is the gametophyte (haploid). The gametophyte on sexual reproduction through gametes produces a diploid zygote which gives rise to the diploid plant, i.e. the sporophyte. The sporophyte on the other hand reproduces by haploid zoospores borne in unilocular sporangium and gives rise to the gametophyte. Thus the two generations (diploid and haploid) alternate with each other. But there are some discrepancies in the life-cycle of *Ectocarpus*. Thus it is seen that the diploid zoospores borne in the plurilocular sporangium give rise to the sporophytes again which bear only plurilocular sporangia with diploid zoospores. In this case the gametophytic generation is omitted. Then again gametes may act as spores (zoospores) and develop parthenogenetically into gametophytes again. In this case the sporophytic generation is omitted. Stages in the life-history are shown below:

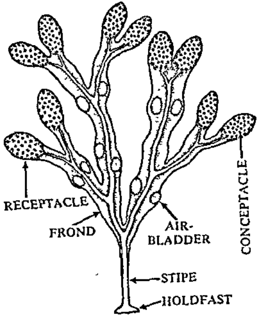
1 Asexual plant ($2n$) → (*a*) zoospores ($2n$) in plurilocular sporangium → asexual plant ($2n$). (*b*) zoospores (n) in unilocular sporangium → sexual plant (n).
2 Sexual plant (n) → isogametes (n) in plurilocular gametangium → (fusion in pairs) → zygote ($2n$) → asexual plant ($2n$).

2. *FUCUS* (*16 sp.*)

Occurrence. *Fucus*, a genus of *Fucaceae*, is a widely distributed marine alga, growing along the coast between the high tide level and the low tide level, being more abundant in temperate seas.

Structure. The *Fucus* plant (FIG. 42) consists of a dichotomously branched thallus, generally 0.3 to 1 m. in length; some species growing below the low tide level may be as big as 4.5 m. The plant body is differentiated into three distinct parts: (*a*) a basal disc-shaped holdfast by which it attaches itself to rocks, (*b*) a long or short *stipe*, *i.e.* the stem-like portion, and (*c*) leathery fronds or laminae, i.e. the flattened portions, provided with a distinct mid-rib. The inflated tip of the frond is called the receptacle. It has some small openings, each leading into a cavity known as the conceptacle. The branches have some swellings here and there along the mid-rib, often close to

dichotomy; these swellings are filled with air and are known as *air-bladders*. They give buoyancy to the plant helping it to float. The body of *Fucus* is composed of parenchymatous cells. Each cell contains a nucleus and a number of plastids which contain *fucoxanthin* in addition to chlorophyll, the former masking the chlorophyll and giving the plant a brown appearance. As a result of photosynthesis a carbohydrate, called *laminarin*, accumulates in the cells. No starch is formed.



Fucus. FIG. 42. A *Fucus* plant. (Dark dots on the receptacle are conceptacles.)

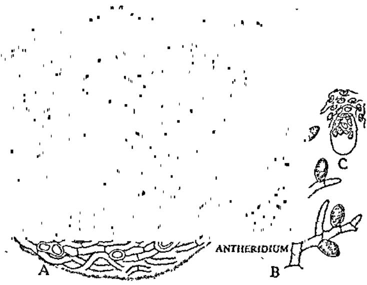
The thallus in section shows a loose mass of elongated cells, collectively known as the *medulla*; it occupies the main bulk of the thallus. The interspaces in the medulla are filled with a gelatinous substance. Surrounding the medulla and lying towards the surfaces there is a compact mass of cells known as the *cortex*. Growth of the thallus takes place by a single pyramidal apical cell.

Reproduction. Asexual reproduction is absent in *Fucus*. Vegetative reproduction is by the fragmentation of the thallus; the detached parts then float on water and vegetate. *Fucus*, however, commonly reproduces sexually by heterogametes—antherozoid and egg—borne respectively by antheridium and oogonium.

Sexual Reproduction. Antheridia and oogonia are borne in special globose or flask-shaped cavities known as the conceptacles which lie embedded in the swollen tip or receptacle of the thallus. Externally the conceptacles appear as small scars. Both antheridia and oogonia may occur in the same conceptacle or in two separate conceptacles borne by the same plant (monoecious), or they may be borne by two separate plants (dioecious).

A conceptacle (FIG. 43A) of monoecious species shows in section the following: (*a*) numerous unbranched multicellular sterile hairs called *paraphyses*, (*b*) an apical opening known as the *ostiole*, (*c*) numerous oval sac-like antheridia borne on small much-branched *antheridial filaments* (FIG. 43B), and (*d*) a number of isolated oval oogonia, each borne on a very short stalk-cell. The antheridium pro-

duces numerous more or less pear-shaped **antherozoids**, generally 64 in number, each with two lateral cilia of unequal lengths. After they



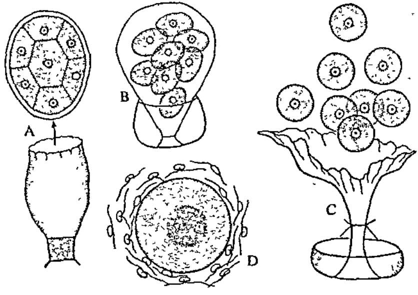
Fucus. FIG. 43. in various stages dia, and paraph antheridia with

are liberated from the antheridium the antherozoids (FIG. 43C) freely swim about in water. Each oogonium (FIG. 44 A-D) is a single large oval cell. Its nucleus divides three times to produce *eight* nuclei. With the cleavage of the cytoplasm each forms a large round egg. The oogonial wall is made of three layers. The outer layer bursts and the oogonium, still surrounded by two inner layers, is pushed out of the conceptacle as a result of swelling of the gelatinous material within the conceptacle. Later the middle layer ruptures at the apex, and as the inner layer imbibes more water it swells and the eggs become rounded off. The inner layer soon dissolves and the eggs are set free. Both antheridia and oogonia are liberated in packets through the ostiole in a quantity of mucilage.

Fertilization. Eggs are large and passive, while the antherozoids are minute, ciliate and active. A vast number of antherozoids swim to the oogonium being attracted by some chemical substance, and get attached to it by one cilium (FIG. 44D). Their vibration around the egg causes the egg to rotate. One or more antherozoids may enter the egg but finally only one fuses with the egg-nucleus. The fertilized egg or zygote clothes itself with a wall, and almost immediately (within a few hours) divides and grows into a new thallus.

Alternation of Generations. There is no alternation of generations in

Fucus. The plant itself is diploid, i.e. sporophytic. Reduction division takes place in the formation of gametes (eggs and antherozoids); so



prior to fertilization. *Redrawn partly after Fig. 171 in* Plant Morphology *by A. W. Haupt by permission of McGraw-Hill Book Company. Copyright 1953.*

the gametes are haploid, i e. gametophytic. The diploid condition is restored in the zygote upon fertilization of the gametes. This diploid condition continues in the *Fucus* plant. Stages in life-cycle are shown below:

Plant ($2n$)→ conceptacle ($2n$)→ $\begin{cases} \text{antheridium } (2n) \rightarrow \text{antherozoid } (n) \\ \text{oogonium } (2n) \rightarrow \text{egg } (n) \rightarrow \text{fusion} \end{cases}$
(fertilization) with an antherozoid→zygote ($2n$)→plant ($2n$).

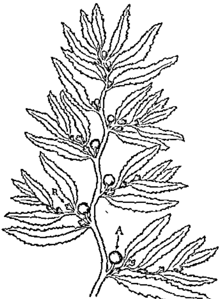
Note that the *Fucus* plant being a sporophyte with diploid chromosomes the so-called antheridium is interpreted as a microsporangium producing small motile microspores which function as antherozoids, and the so-called oogonium as a megasporangium producing large immobile megaspores which function as eggs. *Fucus* is thus heterosporous.

3. *SARGASSUM* (*250 sp.*)

Occurrence. *Sargassum* (FIG. 45) is a common genus of *Sargassaceae* growing in abundance in tropical and sub-tropical seas along rocky coasts. The plant grows to a length of about 6 m. or so and may remain attached to some rocks by a *holdfast* or may be commonly free-floating, often drifted to the coast or far out into the sea. There is a vast accumulation of this plant in the Sargasso

Sea. Columbus was the first to sail through this sea in 1492 despite the fear of his sailors.

Structure. The plant body consists of an axis (stipe) which is much branched. Branching is always monopodial. The stipe and the lateral branches bear a large number of green flattened or cylindrical leafy fronds with wavy serrate margin and a mid-rib. Berry-like air-bladders *develop in small clusters in the axil of* the frond or close to its base; these give buoyancy to the plant to float. Species of *Sargassum* show ranges of forms. Growth takes place by a three-sided apical cell.



Sargassum. FIG. 45. A plant (portion) showing numerous green fronds, air-bladders (*A*) and receptacles (*R*).

Reproduction. *Sargassum* is closely related to *Fucus* and follows the same life-cycle. Vegetative reproduction of this plant is most common and takes place by fragmentation of the thallus. There is no asexual mode of reproduction in *Sargassum*.

Sexual Reproduction. In the axil of the frond or a little beyond, often much-branched receptacles are borne. *Sexual reproduction* takes place by well-developed sex organs (antheridia and oogonia) which occur in hollow flask-shaped cavities called conceptacles borne by the receptacle. *Sargassum* species may be monoecious bearing the sex organs in two distinct conceptacles on the same receptacle or on two separate receptacles, or they may be dioecious with the sex organs being borne by two separate plants. The monoecious condition is, however, more usual than the other. Each conceptacle is provided with a

[illegible]

to form eight nuclei which occupy a peripheral position, and all of them are discharged from the oogonium but only one is functional acting as the egg-

[illegible]

from the oogonial wall. Numerous antheridia develop on branched antheridial filaments in much the same way as in *Fucus* Each antheridium bears 64 antherozoids which are biciliate and more or less pear-shaped; the two cilia are of unequal lengths.

Fertilization takes place outside the plant body, as in *Fucus*, and the process is much the same in both the cases. The resulting zygote *germinates immediately* without any period of rest.

Alternation of Generations. *Sargassum, like Fucus, shows no alternation of*

generations. The plant itself is diploid and the gametes only are haploid. The zygote ($2n$) grows into the plant without any reduction division.

CLASS VII | RHODOPHYCEAE or red algae | about 3,000 sp.

General Characters. Rhodophyceae or red algae form a big group of highly specialized marine algae comprising about 3,000 species. They are very widely distributed in both temperate and tropical seas, more particularly in the latter. Many species form a characteristic belt of vegetation along the sea coast between the high tide level and the low tide level; a good number of species grow at depths of 60-90 m.; a few at much greater depths up to about 180 m. They mostly grow attached to rocks. There are, however, some epiphytic and parasitic forms growing on other algae. Although mostly marine about 50 species have been found to occur in fresh water, mostly restricted to hill streams. Red algae are characterized by red or purplish colour due to the presence of a red pigment called *phycoerythrin* in addition to chlorophyll which is often masked by the other pigment. Many of the red algae contain a small amount of *phycocyanin*, the blue pigment of Cyanophyceae. Freshwater species are green in colour. Red algae show a variety of forms—filamentous, ribbon-shaped, distinctly leaf-like marked with veins, etc. They are mostly a few to about 25 cm. in length; a few are as long as 1-1.3 m.; deep-water ones are much longer. Gelatinous material is abundant in red algae, either occurring within the thallus or forming a sheath in the filamentous forms. Some of the red algae are heavily incrusted with lime. The cells may be uninucleate or multinucleate with one or more plastids which may be with or without pyrenoid. As a result of photosynthesis a sugar or more commonly a special kind of starch called *floridean starch* accumulates in the cells. There is total absence of motile ciliate cells in red algae; zoospores are altogether absent, and the gametes are never ciliate. The peculiar mode of sexual reproduction also makes the life-history more complicated. Members of Rhodophyceae are either haploid, or they show a regular alternation of similar haploid and diploid stages; the latter bear tetrasporangia (see FIG. 47C).

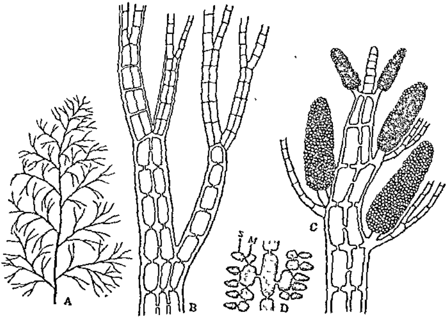
Uses. Red algae are very important from the economic point of view. A gelatinous material obtained from some red algae (e.g. *Gelidium* and *Gracilaria*) is the source of a commercial product known as *agar-agar* which is used as a medium for culture of fungi and bacteria; some preparation of it is used as a food by the Chinese and the Japanese; it is also used in medicines. In recent years it has been put to a variety of uses: as a base for shoe-polish, shaving cream, cosmetics, etc., as a sizing material, emulsifying agent and as a dyeing and printing material for textile goods. In Europe its use for thickening soups is extensive. The agar industry was confined to Japan for many years, but has

recently been extended to the U.S.A., Canada, Australia, New Zealand and South Africa. A few algae are eaten by men as food (e g. *Porphyra* and *Chondrus*) and some used as medicines. They also form an important food for fish.

Origin and Relationship of Rhodophyceae. Rhodophyceae are the most highly specialized group of all algae. The origin of red algae and their relationship with other algae have so far remained a mystery. This is indeed a *unique* group among the algae because of the characteristic type of female organ—the carpogonium, mode of zygotic germination, and absence of ciliate reproductive bodies. This group may have originated from some non-ciliate unicellular ancestor. The primitive red algae have, however, some resemblance with blue-green algae; both have blue pigment and red pigment, primitive type of nucleus, and both are wanting in ciliate reproductive bodies. They differ, however, in many other important characteristics, particularly in the mode of reproduction.

1. *POLYSIPHONIA (150 sp.)*

Polysiphonia (FIG. 46A) is a common marine red alga. Its thallus is cylindrical and much branched (filamentous), attaining a length of



Polysiphonia. FIG.
or siphonic cells v
through them; *C*, ‹
bearing clusters of antheridia; *D*, antheridial branching showing antheridial (spermatial) mother cells (*M*) and spermatia (*S*).

a few to about 25 cm. Many species commonly grow attached to the thallus of *Fucus* and other marine algae. The body is polysiphonous (FIG. 46B) being composed of a central row of elongated cells—the central or axial siphons, and encircling it another layer of more or less similar cells—the pericentral siphons, and hence the

name *Polysiphonia*. The number of pericentral siphons varies from 4-24 according to the species. There are distinct pores and protoplasmic connexions through them between the adjoining cells. The cells are uninucleate and with many red discoidal plastids. Growth takes place by a single apical cell.

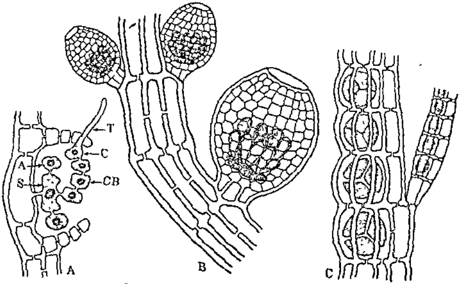
There are three distinct forms of *Polysiphonia* representing three stages in its life-history. One form reproduces by four spores formed in a tetrad, called the tetraspores; the second form is male and bears only antheridia (or spermatangia); and the third form is female and bears carpogonia and later carposporangia with carpospores. *Polysiphonia* is thus heterothallic. No motile ciliate cells develop at any stage. The three forms are alike in general appearance.

Male Plant (FIG. 46C). The antheridia borne near the thallus apex by the male plant occur in dense clusters on one arm (fertile) of a dichotomous branching, while the other arm grows into a long forked sterile branch. The fertile arm is unbranched and considerably elongated, being several cells in length. The cells cut off laterally a number of pericentral cells in an encircling manner. Then each cuts off one or more unicellular antheridial mother cells towards the free surface. Each of them bears 2-4 antheridia (FIG. 46D). The protoplast of each antheridium functions as a single male gamete known as the spermatium.

Female Plant (FIG. 47A). The procarp (the complex female organ of Rhodophyceae—the carpogonium with trichogyne and the associated cells) arises from a cell of the central axis a little behind the apex of the thallus. This first produces a large cell called the *supporting cell* which gives rise to a short, curved, 4-celled branch, called the *carpogonial branch*, of which the terminal cell is the carpogonium with a slender elongated projection at the apex, called the trichogyne. The supporting cell further cuts off a basal cell and an upper cell (auxiliary cell). An envelope develops as an outgrowth of the pericentral cells adjacent to the supporting cell. The nucleus of the carpogonium is the egg-nucleus.

Fertilization. The spermatium on liberation from the antheridium is carried by water current to the trichogyne. The tip of it dissolves and a spermatium passes through it into the carpogonium and finally unites with the carpogonium-nucleus (egg-nucleus). The trichogyne is cut off by a wall at its base, and the fusion-nucleus (diploid) passes into the auxiliary cell. The carpogonium and the branch cells break down, while the auxiliary cell, supporting cell and the other cells fuse into a large irregular cell—the placental cell. From this grow a number of large, elongated, single-celled carposporangia. The contents of each constitute a carpospore, and the nucleus of it is diploid. In the meantime the envelope grows and surrounds the carposporangia as a large urn-shaped pericarp leaving a small opening

or ostiole at the apex. The whole structure consisting of the carposporangia and the pericarp is known as the cystocarp (FIG. 47B).



Tetrasporic Plant (FIG 47C). Carpospores liberated from the carposporangia germinate and develop into tetrasporic plants which are asexual. A *fertile central cell* (siphon) of a tier produces a short-stalked sporangium which lies between the central and the pericentral siphons. Its nucleus undergoes reduction division and four tetraspores are formed in a tetrad. In this way a series of tetraspores may be formed in the fertile filament. On liberation from the sporangium the tetraspores germinate, two of them developing into male plants and two into female plants.

Alternation of Generations. The tetrasporic plant is diploid (or sporophytic). Reduction division takes place in the formation of the tetraspores which evidently are haploid. They grow into haploid (or gametophytic) male and female plants. With the fusion of the gametes the diploid condition is restored in the zygote-nucleus. The diploid number continues into the carpospore. The diploid carpospore grows into the diploid tetrasporic plant, and thus an alternation of generations (haploid and diploid) takes place to complete the life-cycle of *Polysiphonia*. Stages in life-cycle are shown below:

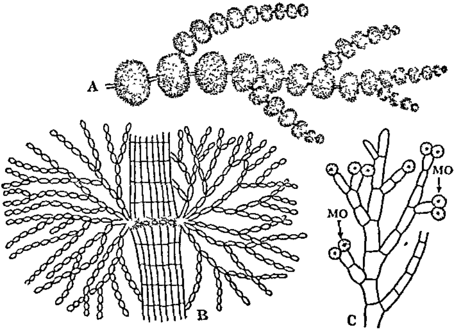
1 Tetrasporic plant ($2n$)→tetrasporangia ($2n$)→tetraspores (n)→male and female plants (n).

2 Male plant (n)→antheridia (n) in clusters→spermatia (n)→fuse with egg-nuclei (n) of female plant.

3 Female plant (n)→procarp (n)→carpogonium (n)→egg-nucleus (n)→fusion (fertilization) with spermatium (n) of male plant→zygote-nucleus ($2n$)→carposporangium ($2n$)→carpospore ($2n$)→tetrasporic plant ($2n$).

2. *BATRACHOSPERMUM* (*40 sp.*)

Batrachospermum (FIG. 48A) is a freshwater red alga commonly found in hill streams. It occurs in a clustered mass very close to a



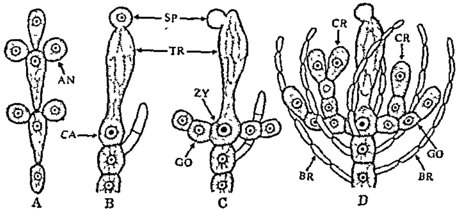
Batrachospermum. FIG. 48. *A*, a plant showing lateral branching and whorls of dwarf filaments; *B*, a whorl (magnified); *C*, the juvenile forms producing monospores.

spring, from where the filaments are carried a long way down the stream. The colour is usually blue-green, but sometimes violet or brown. The cells are uninucleate with parietal lobed plastids, each with a pyrenoid. The thallus, a few cm. in length, is filamentous, and shows monopodial branching. Whorls of short (or dwarf), very delicate filaments arising from each node of the thallus give it a distinct beaded appearance (FIG. 48A) which is clear under a pocket lens or even to the naked eye. Each dwarf filament (FIG. 48B) is much branched and consists of a row of ellipsoidal or narrow and elongated cells, and commonly bears terminally some fine hairs. The thallus remains attached to some hard object by a prostrate shoot which sends off numerous primary thalli floating on water. The basal cells of the whorl of short filaments develop threads of cells which grow downwards over the cells of the thallus, forming a cortex.

Reproduction. *Batrachospermum* reproduces both sexually and asexually. The [illegible] plant—[illegible] reproducing asexually. The juvenile form is a *simple protonema*-like filament (FIG. 48C).

Asexual Reproduction. Asexual reproduction of the juvenile form often takes place by the formation of monospores (FIG. 48C). The monospore is always formed singly within the monosporangium and is really the terminal cell of a short lateral branch growing from the juvenile filament. The latter may reproduce by monospore year after year and remain in this stage, or under suitable conditions of illumination it may give off mature thalli of *Batrachospermum* by lateral branching.

Sexual Reproduction. Antheridia or spermatangia, i.e. the male reproductive organs, develop in small groups at the end of a lateral (short or dwarf) filament (FIG. 49A). The antheridium mother cell,



Batrachos[illegible] 49. A, an antheridial branch bearing antheri- [illegible]

FIG. [illegible] Hill Book Company. Copyright 1935.

produces one or more antheridia terminally. They are uninucleate and usually globose or ovoid in shape. The protoplast of each [illegible] gamete known as the spermatium.

The carpog[illegible] be borne by the same plant that produces the [illegible] thallic), or, it may be borne by another plant (heterothallic). Short lateral branches, called *carpogonial filaments*, consisting of a few cells, are produced from some of the short or dwarf filaments of the whorl. The terminal cell of the carpogonial filament is the carpogo-

nium. The tip of the carpogonium is prolonged into a distinct inflated cell, called the *trichogyne*. All the cells of the carpogonial branch have a dense mass of protoplasm and are uninucleate. The protoplast of carpogonium forms a single uninucleate female gamete.

Fertilization. After escape from the antheridium the spermatium is carried to the carpogonium by water current, and there it is attached to the trichogyne. The contact wall of the trichogyne dissolves and the spermatium passes through it down into the carpogonium and fuses with the female gamete. The trichogyne is cut off by the formation of a plug It is, however, persistent in *Batrachospermum*. The fertilized carpogonium (FIG. 49C) produces a mass of short filaments (gonimoblasts). The terminal cell of a filament is a *carposporangium* (FIG. 49D). The protoplast of each carposporangium is a carpospore. Some of the sterile cells at the base of the carpogonium form an envelope of loose filaments around the carposporangia, and the whole structure consisting of the envelope, gonimoblasts, carposporangia and the fertilized carpogonium is then known as the cystocarp (FIG. 49D). Almost immediately after fertilization the zygote-nucleus representing the only diploid stage of the plant undergoes reduction division, followed by repeated mitotic divisions. Finally a nucleus migrates into a carposporangium. The carpospore, when released, germinates into a simple prostrate protonema-like filament which soon bears erect threads. There is no alternation of generations in *Batrachospermum*.

Chapter 3 BACTERIA

A Short Historical Account. Antoni von Leeuwenhoek (1632-1723) of Delft in Holland was the first to discover bacteria (1653-1673) with the help of the microscope invented and considerably improved by himself (see also p. 130). Louis Pasteur (1831-1895) of France thoroughly established the science of bacteriology. He carried out extensive work on fermentation and decay, and the cause of hydrophobia. About the year 1875 Pasteur made known to the world the importance of bacteria. He was the first to prepare vaccine and use it for the cure of the disease. He saved many Russians from hydrophobia by the use of this vaccine, and the Tsar of Russia in honour of his discovery sent him a diamond cross and also a hundred thousand francs to build a laboratory in Paris—now called the Pasteur Institute. About the same year Robert Koch of Germany proved that anthrax disease so common in cattle was caused by a kind of bacteria. He also showed in 1882 that tuberculosis and Asiatic cholera were caused by bacteria. From that time onwards many workers were attracted to this new science. Prominent among them were Emile Roux—helper of Pasteur, and Emil

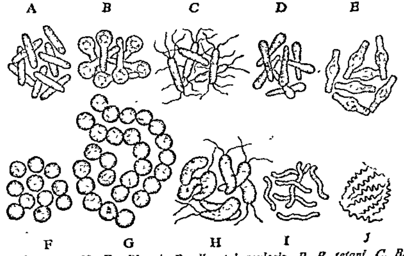
Behring—pupil of Koch, who discovered the diphtheria antitoxin about the year 1894; Elie Metchnikoff of South Russia in the eighties of the last century proved that phagocytes ate up germs and protected the body; Theobald Smith of America discovered in 1893 germs of Texas fever in the blood corpuscles of cows.

Classification of bacteria (*1,500 sp.*)

1 Bacilli (sing. bacillus)—rod-shaped bacteria, e g. *Bacillus tuberculosis, B. tetani, B. typhi*, etc.;
2 Cocci (sing coccus)—spherical bacteria, e.g. *Staphylococcus, Streptococcus, Azotobacter*, etc.;
3 Spirilla (sing. spirillum)—bacteria with spirally wound body, e g. *Spirillum, Spirochaete*, etc ; and
4 Commas—slightly twisted like a comma, e g. *Vibrio cholerae*.

General Description. Bacteria (class Schizomycetes) are the smallest and the most primitive organisms known to us, and number about 1,500 species. They are single-celled—usually spherical, rod-like or branched. In some forms the cells may be united into filaments or masses. There is no definite nucleus in the bacterial cell; chromatin granules representing an incipient nucleus are, however, often present. The cell-wall is made of chitin. Some forms of bacteria are provided with 1 or more cilia (or flagella). Chlorophyll is altogether wanting in them. Many of these micro-organisms are as small as 1 micron or even 0.5 micron, particularly the spherical ones, while the rod-like forms are 2 microns in length on the average (1 micron= 1/1,000 mm. or about 1/25,000 inch). Being so minute in size they are imperfectly seen even at the highest magnification of the microscope.

They occur almost everywhere—in water, air and soil, and in foodstuff, fruits and vegetables. Many of them float in the air; many are



Bacteria. FIG. 50. Bacilli: *A, Bacillus tuberculosis. B, B. tetani. C, B. typhi. D, B. diphtheriae. E, B. anthracis.* Cocci: *F, Staphylococcus. G, Streptococcus.* Comma: *H, Vibrio cholerae.* Spirilla: *I, Spirillum* (common in water). *J, Spirochaete.*

abundant in water; and many are specially abundant in the soil, particularly to a depth of 30 cm., and also in sewage. A few thousands may occur in 1 c.c. of water, and a few millions in 1 gram of soil. Many live within and upon the bodies of living plants and animals. The intestines of all animals always contain a good number of different kinds of bacteria.

Reproduction. There is no sexual mode of reproduction in bacteria. They may repeatedly divide by fission or they may take to spore formation.

(1) *By Fission.* Many bacteria divide by the process of fission (see p. 343). Fission may take place in 1 plane or in 2 or 3 planes. By this method they may multiply rapidly in number. Hay bacillus (*Bacillus subtilis*), for instance, divides 2 or 3 times an hour under favourable conditions. At the minimum rate of division a single cell may give rise to over sixteen million (16,777,216) offspring at the end of 12 hours.

(2) *By Spore Formation* (FIG. 51). Some bacteria form spores which are always 'resting' spores. A small mass of protoplasm within the mother cell clothes itself with a thick membrane, forming an *endospore*. The mother cell soon dissolves. The endospore may remain dormant for months or even several years resisting adverse conditions of life such as high temperature, freezing, extreme dryness, presence of many poisonous chemicals, etc. Then under favourable conditions of moisture, temperature and suitable food the endospore enlarges, and its contents form a full-fledged bacterial cell.

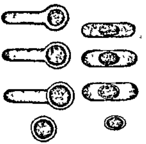


FIG. 51. Spore formation in two types of bacteria.

Physiology of Bacteria. Bacteria are lacking in chlorophyll and thus are mostly unable to utilize carbon dioxide for synthesis of organic compounds for their food. They are mostly *heterotrophic* (see p. 289) in habit, leading a saprophytic or parasitic life. A small number are, however, *autotrophic*, being able to manufacture organic food compounds for themselves. Saprophytic bacteria commonly live in water and soil containing organic compounds of plant or animal origin, in dead bodies of plants and animals, in vegetables and fruits in storage particularly, and in a variety of other media. They secrete enzymes to bring about the digestion of carbohydrates, proteins and fats, and absorb the digested products. Parasitic bacteria infect living plants and animals and absorb organic food compounds from their body by the same process of enzyme-secretion and digestion.

Harmful Effects of Bacteria. Many parasitic (or pathogenic) bacteria

infect living plants and animals, particularly the latter, and cause various and often serious diseases in them, sometimes in epidemic form. Normally they infect the host through wounds or they may be breathed in or taken in with food, water and milk. After infection of the body they produce a toxin (poison) which causes many of the serious diseases in human beings and domestic animals. Some of the common disease-producing bacteria are: *Bacterium dysenteriae* causing dysentery, *B. influenzae* causing influenza, *B. diphtheriae* causing diphtheria, [illegible] ing, tubercul[illegible] causing teta[illegible], etc. Some [illegible] ing bacteria) are possibly the deadliest enemy of mankind. They have the remarkable power of dissolving the red corpuscles of the human blood, and are responsible for erysipelas and extremely dangerous kinds of blood-poisoning.

Parasitic bacteria also attack plants and cause various diseases such as fire blight of apple and pear, ring disease of potato, black rot of cabbage, canker of *Citrus* (orange), etc. In plants, however, fungal diseases are far more common than bacterial diseases, while in animals the reverse is the case. Many bacteria are also responsible for decay of vegetables, fruits, meat, cooked food, etc., particularly during summer months.

Autotrophic Bacteria. Some bacteria obtain energy by the breakdown (oxidation) of certain chemical substances and utilize this energy for the manufacture of food substances from carbon dioxide and other inorganic compounds present in the soil; while others utilize energy from light for the same purpose. Thus **sulphur bacteria** oxidize hydrogen sulphide to free hydrogen and then sulphuric acid which in the soil transforms into sulphate as a source of plant food. The energy thus obtained by oxidation is utilized in the synthesis of organic compounds, as stated above. Similarly **iron bacteria** and **hydrogen bacteria** oxidize iron compounds and molecular hydrogen and utilize energy by these oxidative processes. **Nitrifying bacteria** of two types oxidize ammonia to nitrite and nitrite to nitrate in two stages. **Purplish sulphur bacteria** and **greenish bacteria** on the other hand utilize light energy for the synthesis of organic compounds for their own use; they oxidize sulphuretted hydrogen in the presence of light.

Beneficial Effects of Bacteria. Although some bacteria (the disease-producing ones) are most harmful a large number of them are most useful in various ways, particularly in agriculture and some industries. Many bacteria are nature's scavengers.

(1) Agricultural. (*a*) **Decay of Organic Substances.** But for the most useful work of many bacteria the dead bodies of plants and animals would remain unaltered covering possibly the whole or at least a very large part of the earth's surface leaving very little room for anything or anybody else; in addition, the organic compounds contained in such dead bodies would remain permanently locked up in them without any further use. Fortunately, however, bacteria play

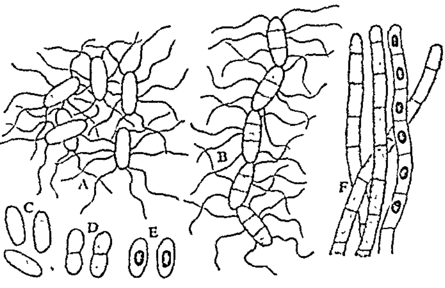
a most important role in this direction. They act on these bodies, reduce the various organic compounds to simple forms such as nitrates, sulphates, phosphates, and release them to the soil for utilization by green plants again in food manufacture. Carbon dioxide, water, oxides of nitrogen or even free nitrogen formed in the process, however, escape unused. (*b*) **Nitrification.** Proteins contained in the dead bodies of plants and animals are acted on by different kinds of bacteria and converted into ammonium compounds (ammonification) and then oxidized into nitrite and nitrate (nitrification) suitable for absorption by the green plants (see p. 249). (*c*) **Nitrogen Fixation.** Fixation of free nitrogen of the air by many soil bacteria like *Azotobacter* and *Clostridium* directly in their own bodies, and *Rhizobium* (nodule bacteria) in association with the roots of leguminous plants is very important from an agricultural standpoint (see p. 251). (*d*) **Fertilizers.** Conversion of cowdung, animal excreta into manures, and formation of humus or leaf-mould, as sources of nitrogen especially, are due to bacterial activities (see p. 243). Many chemical changes in the soil which make it fertile are mainly due to the activity of bacteria (and also of many other organisms in the soil). In fact the fertility of the soil may largely be attributed to the presence of bacteria in it.

(2) **Industrial.** From an industrial standpoint also many bacteria are most useful. Curing and ripening of tobacco leaves, fermentation of tea leaves, ripening of cheese, etc., for their characteristic flavours, retting of fibres, formation of vinegar from alcohol by acetic acid bacteria (*Mycoderma*), fermentation of sugar into alcohol by yeast and a few bacteria, curdling of milk by lactic acid bacteria, conversion of hide into leather during the process of tanning and such other cases of fermentation are specially important.

(3) **Medical.** We are normally protected against virulent germs by many of the good bacteria which live as permanent flora in different parts of our body from childhood. Thus different and distinct types of such bacteria form their permanent abode in the mouth, respiratory tract, intestines, etc., and guard these passages against invasion by the disease-producing germs by waging chemical warfare against them, saving us from falling a prey to such deadly types. They kill the foreign invading germs by secreting from their body certain specific chemical poisons—the antibiotics.

Hay bacillus (*Bacillus subtilis*) is a common form of saprophytic bacteria growing in a decoction of hay. It can be easily grown in the laboratory by soaking hay in water and boiling it; the spores of hay bacillus withstand prolonged boiling. The decoction may then be kept in a warm place for a day or two. One or two drops may then be examined under a microscope at high magnification. Hay bacillus is unicellular and rod-shaped, provided with a number of flagella all over its body. The cells may be held together in chains. There is a granular vacuolated mass of protoplasm with chromatin granules but no definite nucleus.

While growing in the fluid hay bacillus reproduces by fission. The cell undergoes constriction in the transverse plane and is split up into two. The process of fission may be repeated several times and numerous cells formed within a short time. It is seen that the cells overcrowd the liquid and tend to come to the surface. They lose their cilia and become non-motile. Their walls become gelatinous and the cells are held together in long chains. Several such chains form a mucilaginous mass, called a *zoogloea*, which floats as a thin film or



scum on the surface of the liquid. When food is exhausted, the bacillus cells form 1 or 2 spores, called *endospores*, within the mother cell. The protoplasm withdraws from the wall and clothes itself with a fresh firm wall which can resist the action of high temperature and many poisonous substances. Later under favourable conditions the spore germinates in a suitable medium. The wall of the mother cell decays and the spore is liberated, The tough coat of the spore splits and the protoplasm escapes into the surrounding medium. Cilia are formed and the bacillus cell leads an active life.

Viruses. Viruses are the smallest, simplest and possibly the most primitive living organisms yet known to science. They are very much smaller than bacteria, and cannot be detected even under the most powerful microscope. Their presence is revealed only when they produce certain diseased conditions in the plant or the animal. Mayer in 1886 first described the virus disease of tobacco and called it 'tobacco mosaic'. In 1892 Iwanowski first demonstrated that the sap of the affected tobacco plant filtered through a bacteria-proof filter could infect healthy tobacco plants. Beijerinck in 1899 showed that the dried sap containing virus retains the power of infection. According to him the virus is carried through phloem from one part to another. By 1933-34 several virus diseases were discovered. The virus infection may spread from cell to cell by diffusion, while the original source of infection is commonly through biting or sucking insects,

as first shown by Takami in 1901. In the living cells of plants and animals they grow and multiply, and produce various disease symptoms. Bawden in 1936 first isolated nucleoproteins from the sap of the affected part. Recent investigations using the electron microscope and X-ray photograph have revealed the fact that a virus contains a core of nucleic acid surrounded by a very thin film of protein—a condition essential for life and transmission of hereditary properties. Viruses can be purified and obtained *in the form of crystals like many* organic substances. Some human diseases such as mumps, smallpox, chickenpox, measles, yellow fever, scarlet fever, infantile paralysis, influenza, common cold, cancer, hydrophobia, etc., are supposed to be caused by viruses. Among the plants the mosaic diseases of tobacco, sugarcane, potato, tomato, gourds, cucumber, groundnut, etc., spike disease of sandalwood, yellow disease of peach, curly top of cotton, beet, radish, cabbage, turnip, etc., and necrosis (necrotic disease) of potato and tomato are said to be caused by viruses.

Chapter 4 FUNGI

A Short Historical Account. Among the earliest workers mention may be made of **Gleditsch**, a German botanist, who attempted in 1753 a short classification of fungi. **Fontana**, an Italian scientist, worked assiduously for several years on rusts of cereals and published his account in 1767. Serious studies on fungi started from the early part of the 19th century. **Persoon** working in Paris published his first account of fungi in 1793, *Synopsis Methodica Fungorum* in 1801, edible and poisonous mushrooms in 1818, and European fungi and a somewhat detailed classification of fungi from 1822-8. **Fries'** system of classification (1821-32) and later his elaborate work on Hymenomycetes of Sweden (1857-63) gave impetus to many for further study of mycology. **Berkeley** (1803-89), a great British mycologist, published his *Cryptogamic Botany* in 1857 and *Outlines of British Fungology* in 1860. Besides, **Cooke's** (1825-1914) *Handbook of British Fungi* published in 1871, *Handbook of Australian Fungi* in 1892, Cryptogamic Journal *Grevillea* (1884-90), his extensive collections and elaborate drawings at Royal Botanic Gardens, Kew are of outstanding merit. Special mention should be made of **De Bary** (1831-88), professor of botany at Halle and later at Strassburg, who did extensive work on mycology, mostly of a physiological and biological nature, and was the leading mycologist of the period. His new classification of fungi was published in 1884. His investigations on Uredinales and Ustilaginales cleared up many early misconceptions about them, and he was the first to establish heteroecism in rusts in 1864. He also introduced methods of culture of fungi. De Bary also discovered an association of algae and fungi in lichens. He actually laid the foundation of modern mycology. The technique of culture was further advanced by **Brefeld** (1839-1925) and **Van Tieghem** (1839-1914); the former introduced the agar method and the latter the glass-cell method. **Dangeard** about 1893 or so discovered sexuality in Uredinales and Ustilaginales, and later in Ascomycetes and Basidiomycetes. **Blackman** in 1904 discovered a kind of alternation of generations in rusts. **Blakeslee** in 1904 discovered hetero-

thallism in *Mucor* and allied fungi, and he designated the two strains as + and −. Subsequently other investigators noticed the same phenomenon in some other fungi. The importance of mycology in agriculture and certain industries and also as an academic study has been realized and many specialists all over the world have undertaken investigations on fungi in the current century.

Classification of Fungi (90,000 sp.)

Class I Myxomycetes or slime fungi (over 300 sp.).

Class II Phycomycetes or alga-like fungi (1,500 sp.) Sub-class (i) Zygomycetes (reproduction isogamous). Order 1. Mucorales, e g. *Mucor* and *Rhizopus* (moulds). Sub-class (ii) Oomycetes (reproduction oogamous). Order 2. Saprolegniales, e.g. *Saprolegnia* (water mould). Order 3. Peronosporales, e.g. *Pythium*, *Phytophthora* and *Albugo* (= *Cystopus*).

Class III Ascomycetes or sac fungi (25,000 sp.) Sub-class (i) Protoascomycetes (no ascocarp; asci naked). Order 1. Saccharomycetales, e.g. yeast (*Saccharomyces*). Sub-class (ii) Euascomycetes (asci in ascocarp). Series (1) Plectomycetes (closed ascocarp—cleistothecium; no hymenium; asci scattered). Order 2. Aspergillales, e.g. *Penicillium* and *Aspergillus*. Series (2) Pyrenomycetes (ascocarp with an apical opening—perithecium; asci in hymenial layer). Order 3 Erysiphales, e.g. *Erysiphe*. Order 4. Sphaeriales, e.g. *Xylaria*. Order 5. Hypocreales, e.g. *Claviceps*. Series (3) Discomycetes (open ascocarp—apothecium; asci in hymenial layer). Order 6. Pezizales, e g. *Peziza*.

Class IV Basidiomycetes or club fungi (23,000 sp.). Sub-class (i) Hemibasidiomycetes (basidia septate or divided; teleutospore germinating into promycelium which bears basidiospores). Order 1. Ustilaginales or smuts (700 sp.), e.g. *Ustilago*. Order 2. Uredinales or rusts (4,600 sp.), e g. *Puccinia*. Sub-class (ii) Holobasidiomycetes (basidium simple, club-shaped, directly bearing basidiospores; karyogamy and meiosis occur in the basidium). Series (1) Hymenomycetes (basidia on distinct hymenium). Order 3. Agaricales (7,000 sp.); it includes various forms of gill fungi, e.g. mushrooms (*Agaricus*, *Amanita*, etc.), coral fungi (*Clavaria*), and various forms of pore fungi (*Polyporus*, *Polystichus*, *Fomes*, *Boletus*, etc.). Series (2) Gasteromycetes (hymenium indistinct; fruit body remains enclosed by peridium, i e. distinct outer wall). Order 4. Lycoperdales, e.g. puff-balls (*Lycoperdon*). Order 5. Phallales, e.g. stinkhorns (*Phallus*). Order 6 Nidulariales, e.g. bird's nest fungi (*Nidularia* and *Cyathus*). Gasteromycetes are regarded as the highest of all fungi.

Class V Deuteromycetes or fungi imperfecti (over 24,000 sp.), i e. fungi with imperfect life-history (sexual stages being unknown), e.g. *Helminthosporium* and *Fusarium*. They commonly reproduce by conidia. Many of them form important plant and animal diseases.

General Description. Fungi are a group of thallophytes lacking in chlorophyll. They may develop a variety of other pigments in the cell-wall or in the cell-cavity, and have an infinite variety of shapes [illegible] . Being non-green, they [illegible] aprophytes or as parasites. The [illegible] form of *glycogen* (and

not starch). Saprophytic fungi grow in a variety of situations, and thrive under conditions of moisture, warmth and supply of organic food. Parasitic fungi on the other hand grow on living plants (wild or cultivated) and also on animals including human beings. They have the remarkable power of disintegrating or dissolving almost anything they attack by the secretion of suitable enzymes. Parasites that pass their entire life on living hosts are called *obligate parasites*, e.g. rusts; while those that normally live upon living hosts but may lead a saprophytic life, if need be, are called *facultative parasites*, e.g. some smuts. The plant body except the unicellular forms is commonly made of an interwoven mass of very fine and delicate threads called **hyphae**, collectively called **mycelium**. The wall of the hyphae may be made of chitin or pure cellulose.

Reproduction. *Vegetative reproduction* may take place by fragmentation of the body of the fungus or by detachment of a part of it or by budding or in some cases by special bodies called sclerotia. A **sclerotium** is a compact, often hard and rounded, mass of hyphae, with sometimes a dark firm outer covering layer but normally without any spore in it. It varies in size from a small pin-head to a few or sometimes several cm. in diameter, and gives rise to mycelium or fruit-body. *Asexual reproduction* takes place by means of spores of varied nature: (*a*) ciliate spores or **zoospores**, (*b*) ordinary **spores**, sometimes called gonidia, borne often in large numbers in a case called sporangium, (*c*) **conidia** formed singly or in groups or chains by specialized hyphae or conidiophores at their tips by the process of abstriction, (*d*) **chlamydospores** are thick-walled resting spores formed singly or in a chain by certain vegetative hyphae; these are transformed vegetative cells, (*e*) **oidia** are short segments of a vegetative hypha, functioning as spores, (*f*) **ascospores** are spores, usually 8 in number, formed in a sac called ascus, and (*g*) **basidiospores** are spores, usually 4 in number, formed externally by a club-shaped basidium on short slender stalks called sterigmata. There are also other kinds of specialized spores. *Sexual reproduction* in fungi shows three distinct phases: (*a*) **plasmogamy** which is the fusion of two protoplasts with or without nuclear fusion; by this process two haploid nuclei (called a **dikaryon**) of opposite sexes are brought together in one cell; dikaryotic condition may continue for a considerable length of time, as in higher fungi (e.g. *Puccinia*), or the two nuclei may fuse almost immediately, as in lower fungi (e.g. *Mucor* and *Phythium*); (*b*) **karyogamy** which is the fusion of the two nuclei of a dikaryon resulting in a diploid (zygote) nucleus; this is sooner or later followed by meiosis to revert to the haploid condition; (*c*) with the development of gametangia and gametes sexual reproduction may be **isogamous**, **anisogamous** (rare) or **oogamous**.

Characteristics of the Main Groups. Phycomycetes. Phycomycetes are

the lowest group of fungi. Their vegetative mycelium is mostly unseptate and multinucleate (coenocytic), and the hyphae loosely or closely interwoven. Asexual reproduction is by ciliate zoospores or by spores of different kinds (see p. 439) formed in large numbers in a unicellular sporangium. Sexual reproduction is either isogamous resulting in the formation of a zygospore, as in Zygomycetes, or oogamous resulting in the formation of an oospore, as in Oomycetes.

Ascomycetes. The vegetative mycelium is septate and multicellular, and the hyphae loosely interwoven. The septa are, however, often incomplete having a central perforation. The cells are uninucleate or multinucleate. Asexual reproduction is characteristically by ascospores (commonly 8 in number) formed in a sac-like structure called ascus; in Ascomycetes many species also reproduce by conidia. No zoospores or ciliate cells are formed in this group. The fruiting body producing the asci is called the **ascocarp.** It has a sterile envelope (see FIG. 71D). An open ascocarp, commonly cup-shaped or saucer-shaped, is called the **apothecium**, as in *Peziza* (see FIG. 72); a closed ascocarp, commonly spherical or oval or flask-shaped with a small apical opening, is called the **perithecium**, as in some Pyrenomycetes (e.g. *Claviceps*, *Xylaria*, etc.); and a completely closed ascocarp is called the **cleistothecium**, as in *Aspergillus* (see FIG. 70D). Sexual reproduction in this group is on the decline. It ranges from oogamy to complete suppression of sexual organs, and finally it becomes reduced to the fusion of two closely associated nuclei (a dikaryon) derived from two parent cells. The fusion nucleus divides thrice to form 8 nuclei which develop into 8 ascospores.

Basidiomycetes. Basidiomycetes are the highest group of fungi. The mycelium is always septate and multicellular, and profusely branched forming an interwoven mass of hyphae. The cells are binucleate. Asexual reproduction is characteristically by **basidiospores** usually borne in groups of four on a club-shaped structure called the basidium. Sexual reproduction and also zoospores are altogether wanting in this group. Sexuality is reduced to the fusion of two undifferentiated but closely associated nuclei (a dikaryon) in the young basidium, and the fusion nucleus divides twice to form 4 nuclei, finally one migrating to each basidiospore. The lower Basidiomycetes, e.g. rusts and smuts, are mostly parasites; while the higher Basidiomycetes, e.g. mushroom, toadstool, puffball, pore fungus, etc., are mostly saprophytes.

Clamp Connexion (FIG. 53). This is a common feature in most types of Basidiomycetes except the rusts. Clamp connexion is a special mechanism by which the sister nuclei of a dikaryon become separated into two daughter cells. This mechanism is found in the secondary mycelia which consist of typically binucleate cells. The binucleate condition has originated from the fusion of two uninucleate cells of two primary hyphae without, however, any ~~karyogamy, i.e.~~ without the fusion of nuclei. Clamp connexion is usually formed in the terminal

cells of the hyphae. In some cases, however, it occurs in most of the cells of the secondary hyphae, sometimes only in some cells here and there. Between the two nuclei a short branch arises forming a sort of hook (clamp cell). One nucleus passes into the clamp cell, *and now both the nuclei divide* simultaneously. The clamp cell bends over and its end touches the wall. This bridge-like short connexion (branch) is called the clamp connexion. Now one nucleus of each pair approaches the other, one evidently passing through the bridge. After this migration a septum is formed at the base of the clamp cell *and another septum below the bridge*, thus separating a pair of nuclei, one from each parent cell.

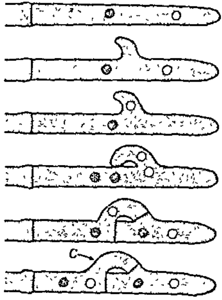


FIG. 53. Clamp connexion (*C*)

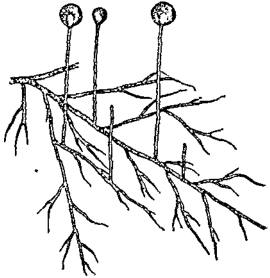
Origin of Fungi. Regarding the origin of fungi no definite statement can be made. There are two views in this respect. According to one view the fungi have been derived from algae. In this connexion it is said that Phycomycetes have arisen from Chlorophyceae, possibly Siphonales, by the loss of chlorophyll which evidently has brought about a change in the mode of nutrition but not in the mode of sexual reproduction, the latter showing parallelism in development in both the groups. The second view is that since primitive Phycomycetes (which are Chytridiales —unicellular) bear uniflagellate zoospores and gametes resembling protozoa (green algae are never uniflagellate) they may have been derived from some uniflagellate organisms like protozoa. If this is so, fungi must have followed an independent line of development (evolution) standing midway between animals and plants. Regarding the origin of Ascomycetes there are again two views. According to one view Ascomycetes may have been derived from some red algae since there are marked similarities in the sexual characters between these *two groups. Another view which is more generally accepted is that Asco*mycetes have arisen from oogamous Phycomycetes. Regarding Basidiomycetes there is general agreement among mycologists that these have been derived from Ascomycetes since there is a close resemblance in the development of the basidium and the ascus, the ultimate difference (or rather, evolutionary tendency) being that basidiospores (4 in number) are exogenous, while ascospores (8 in number, sometimes 4) are endogenous.

CLASS I | MYXOMYCETES or slime fungi | about 400 sp.

Myxomycetes, commonly called slime fungi, form a peculiar group of organisms which are animal-like in their vegetative stages and plant-like in their reproductive stages. Slime fungi are widely distributed growing in damp shady places in

stale moist bread, rotten fruits, shed flowers and other organic media, spreading like a cobweb. It can be easily grown in the laboratory in a piece of moist bread kept under a bell-jar in a warm place for 3 or 4 days.

Structure. The plant body is composed of a mass of white, delicate, cottony threads collectively known as the **mycelium** (FIG. 54). It is always very much branched, but is coenocytic, i.e. unseptate and



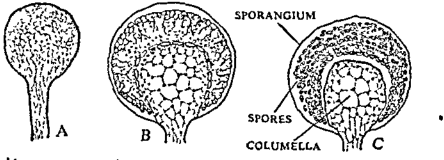
Mucor. FIG. 54. Ramifying mycelia with some sporangia (or gonidangia).

multinucleate. Each individual thread of the mycelium is known as the **hypha** (pl. hyphae).

Reproduction. This takes place by two methods, viz. asexual and sexual. The asexual method is most common.

Asexual Method. *This method of reproduction takes place by* means of spores (or gonidia) which develop in a case, called **sporangium** (or gonidangium), under favourable conditions of moisture and temperature. It is seen that mycelia give off here and there numerous slender *erect* hyphae, called sporangiophores, each ending in a *spherical head—the sporangium* (FIG. 55). *In the formation of the* sporangium the apical portion of each of these hyphae swells out into a spherical head (FIG. 55). As the hypha begins to swell the protoplasmic contents migrate to its tip, but accumulate more densely towards the periphery, the central part remaining comparatively thin *and vacuolate. Later a row of vacuoles is formed around the central* part and these soon fuse up. Consequently a cleft is formed between the outer denser portion and the inner thinner portion, thus separating them. The central portion which is dome-shaped and sterile, i.e. without spores, is called the **columella.** The peripheral protoplasm now gives rise to a number of small, multinucleated, angular

masses by cleavage. Each multinucleated mass becomes rounded off and covered by a wall forming a spore. Its wall thickens and darkens. The wall of the sporangium is thin and brittle. Finally as the columella swells due to accumulation of a quantity of fluid in it, it exerts a considerable pressure on the wall of the sporangium which as a consequence bursts, setting free the spores. The spores are blown



[illegible] columella.

about by the wind. The columella persists for some time after the bursting of the sporangium. The spores being very minute, light and dry, float about in the air, and under favourable conditions they germinate in suitable medium directly into the *Mucor* plant. Sometimes hyphae develop from the columella when the **sporangiophore** (i.e. the slender erect stalk of the sporangium) happens to fall over and these hyphae then bear the sporangia.

Sexual Method. Sexual reproduction takes place by the method of **conjugation** (FIG. 56), only under certain conditions, particularly when the food supply becomes exhausted. Conjugation consists in the fusion of *two similar* gametes, i.e. isogametes (cf. *Spirogyra*). The process is as follows: when two hyphae borne by two different plants of opposite sexes (called the + strain and the − strain) come close together, two short swollen protuberances, called the conjugating tubes or *progametes* (see FIGS. 56*A-B* & 58) develop forming a contact at their tips. As they elongate they push the parent hyphae apart from each other. Each progamete enlarges and becomes club-shaped. Soon it is divided by a partition wall into a basal suspensor and a terminal **gametangium** (FIG. 56*C*). The protoplasmic contents of each gametangium constitute the gamete. The gametes are multinucleate and are called *coenogametes*. The two gametes are identical in all respects. The end- (or common) walls of the two gametangia become dissolved, [illegible] form a **zygospore** [illegible] body, and its wall thickens, [illegible] It contains an abundance of food, particularly fat globules.

It has been observed that sometimes no sexual reproduction takes place even though the fungus grows under all favourable conditions. The investigations of the American botanist, Blakeslee (1904), have revealed the fact that there are two different strains or races of the fungus (the + strain and the — strain) and

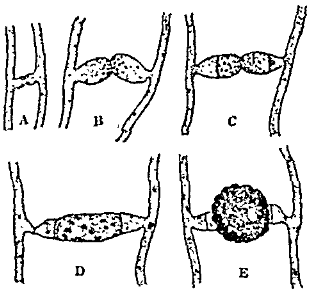


FIG. 56

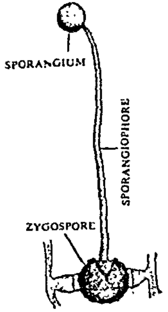


FIG. 57

Mucor. FIG. 56. Conjugation: *A-E* are stages in the process; note the thick-walled zygospores at *E*. FIG. 57. Germination of zygospore.

that sexual reproduction only takes place between the hyphae of these two *different strains, apparently of opposite sexes. Evidently these two strains formed* from separate spores—some giving rise to the *plus* strains and the others to the *minus* strains—must grow together (FIG. 58). Morphologically there is no difference between these two strains, excepting that the + strain (regarded as female) shows a little more vigorous growth than the — strain (regarded as male), but physiologically they are different behaving as two opposite sexes. Such species *are said to be heterothallic, and the condition is designated as heterothallism.* Heterothallism has also been found in certain Ascomycetes (e.g. *Ascobolus* and *Aspergillus*) and Basidiomycetes (e.g. rust fungi). There are, however, many species which form zygotes by the conjugation of the hyphae of the same mycelium. Such species are said to be homothallic.

Sometimes it so happens that although the conjugating hyphae meet, no fusion of gametes takes place. The gametangia then develop parthenogenetically (see p. 344) into thick-walled bodies called azygospores (cf. *Spirogyra*). The azygospore looks similar to the zygospore. Sometimes the free end of a hypha may produce a solitary azygospore. Germination of the azygospore in *Mucor* has not been followed.

Germination of Zygospore (FIG. 57). The zygospore undergoes a

period of rest and then germinates. The outer wall bursts and the inner wall grows out into a tube, called the sporangiophore or promycelium, which ends in a single sporangium. The sporangiophore may

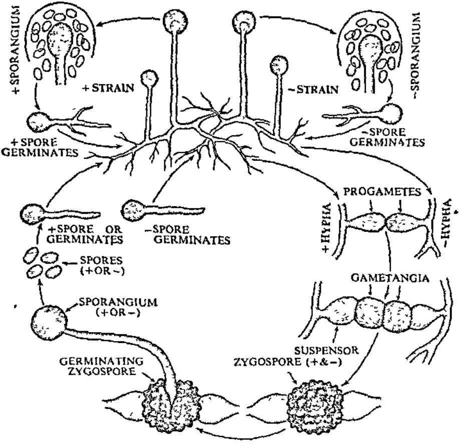


FIG. 58. Life-cycle of *Mucor*.

be branched, each branch bearing a sporangium. The sporangium contains numerous small spores but no columella. The spore germinates, giving rise to the *Mucor* plant.

Blakeslee also found that in heterothallic species all the spores of a sporangium give rise to either + mycelia or to − mycelia, but not both. The zygote is diploid and contains material of both the + strain and the − strain. It undergoes reduction division at the initial stages of its germination, and of the four nuclei so formed three degenerate. Evidently the surviving one (+ or −) by repeated mitotic divisions gives rise to + spores or − spores, and finally to a + strain or a − strain, as the case may be.

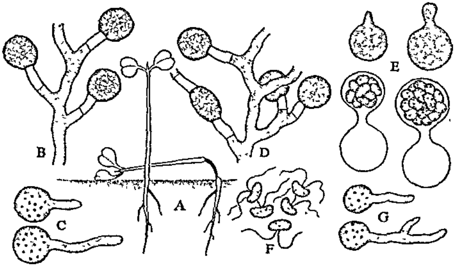
Torula condition (*torula*, a small swelling). It is sometimes seen that under favourable conditions the mycelium of *Mucor* becomes segmented into a short chain of cells. These cells either then swell up, becoming thick-walled and large (chlamydospores), or remain thin-walled and small (oidium cells). Chlamydospores are resting spores and they germinate normally giving rise to the myce-

lium; but oidium cells separate from each other, multiply by budding like the yeast cells, and, like the latter again, set up alcoholic fermentation; the formation of oidium cells and their activity take place specially when the hyphae are immersed in a nutritive liquid.

Rhizopus nigricans (family *Mucoraceae*), a common black mould, is found growing on moist stale bread, decaying vegetables and fruits, jelly, male inflorescence of jack and other organic media. It has the same life-history as that of *Mucor*.

2. *PYTHIUM* (40 sp.)

Pythium (family *Pythiaceae*) is a parasitic fungus, commonly attacking seedlings of cress and mustard at the base of their hypocotyl (FIG. 59*A*), under conditions of over-crowding and over-watering. It causes the disease commonly known as the 'damping-off' of seedlings. Members of *Cruciferae* are particularly susceptible to this disease; other crops like tobacco, ginger, etc., are also infected by this fungus. The most common species of *Pythium* causing the 'damping-off' is *P. de Baryanum*. When attacked, the seedlings become weakened at their base and soon fall over. At first the fungus is a parasite, but later after the death of the host seedlings it thrives on them as a saprophyte. The mycelium ramifies in all directions through the



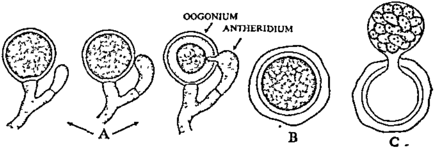
zoospore germinates by producing a germ tube.

intercellular spaces, penetrating here and there into the living cells. At a later stage white cottony threads (hyphae) may be seen on the surface of the seedlings. The long, slender, much-branched hyphae are unseptate and coenocytic enclosing many small nuclei (cf. *Mucor*).

Reproduction takes place both asexually and sexually.

Asexual Reproduction (FIG. 59*B*-*G*). Here and there the mycelium sends out aerial hyphae through the stomata or the cuticle, which bear short lateral branches, each swelling into a spherical head. This head which is partitioned off at the base by a septum may act as a conidium (*B*) or a zoosporangium (*D*) according to external conditions. (*a*) Under moist conditions it acts as a zoosporangium; it protrudes and bulges out into a bladder-like vesicle (*E*). The protoplasm migrates into it and divides to form a number of small naked uninucleate and biciliate zoospores. The zoospores, when set free, swim about in water for a short time (*F*). Soon they withdraw their cilia and clothe themselves with a wall. Eventually they infect a new seedling and germinate by putting forth a short hypha or *germ tube* (*G*) which branches freely within the tissue of the host. (*b*) Under dry conditions the head instead of forming zoospores behaves as a conidium (or conidiospore). It directly infects a new seedling and produces a germ tube (*C*) which branches freely within the tissue of the host.

Sexual Reproduction (FIG 60). After the death of the host the fungus leads a saprophytic life and takes to sexual reproduction



possibly due to starvation. Within the dead tissues of the host or outside them, the hyphal end swells into a spherical head due to migration of a large mass of protoplasm, forming the female organ, called oogonium (*A*). It is cut off from the supporting hypha by a partition wall. The oogonium may also be formed as an intercalary swelling of a hypha. The cytoplasm of the oogonium soon becomes differentiated into two *distinct regions: a central denser region with a nucleus*, constituting the egg or oosphere, and a peripheral region with many small nuclei, constituting the periplasm. From the same hypha or from another close to the oogonium a small branch arises. It swells and becomes more or less club-shaped, and is cut off by a septum at the base. This is the male organ, called antheridium. Its protoplast

The cilia are attached laterally on the zoospore. After escape from the sporangium the zoospores swim about; soon they lose their cilia and form a wall. They germinate by giving out a *germ tube* which passing through a stoma penetrates into the tissue of the leaf (FIG. 62*D*). Sometimes the sporangia germinate directly, pushing out a germ tube. The disease thus spreads rapidly from plant to plant. Sporangia and zoospores are short-lived, and the fungus hibernates in the potato tuber.

Sexual Reproduction. Sexual reproduction takes place by means of oogonia and antheridia (FIG. 63). The oogonium is spherical or pear-shaped with a smooth and reddish-brown wall; it contains within it a large free oosphere or egg surrounded by a scanty zone of periplasm. All the nuclei of the oogonium except one egg-nucleus of the oosphere degenerate. The antheridium is broadly club-shaped, and develops before the oogonium. Finally it contains only one male nucleus, other nuclei originally present having degenerated. The antheridium, as it grows, penetrates into the oogonium. The former, as it swells, surrounds the stalk of the latter like a collar. When such is the case, fertilization is said to be *amphigynous* (as opposed to paragynous when the antheridium and the oogonium lie separate), and it occurs in the following way. The antheridium forms a narrow fertilization tube which penetrates into the oosphere. The male nucleus escapes and fuses with the egg-nucleus of the oosphere. After fertilization the oospore that is formed lies loosely in the oogonium. Germination of the oospore has not been observed yet. Sometimes the antheridium is not formed. The oospore may then develop parthenogenetically.

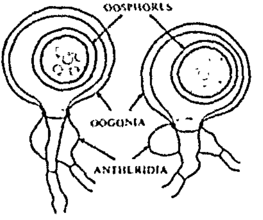


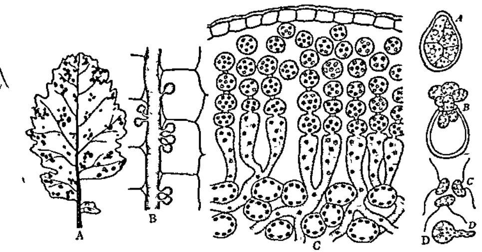
FIG. 63. Sexual reproduction in *Phytophthora*.

Control of the Disease. (1) *Spraying.* The disease may be controlled by spraying the plants, when they are 15-20 cm. high, with Bordeaux mixture which contains copper hydroxide. Spraying should be repeated every 10 or 15 days. (2) *Selection of Seed-tubers.* Tubers suspected to be diseased should be avoided. Seed-tubers obtained from non-infected areas are the best in this respect. (3) *Low Temperature.* Storage of seed-potatoes at a low temperature, 4-5°C., is also practised.

4. *ALBUGO* (25 *sp.*)

Occurrence. *Albugo* (=*Cystopus*) *candida* (FIG. 64), more commonly known as 'white rust', is a parasite, attacking several plants of mustard family such as mustard, radish, cabbage, turnip, etc. White blisters on the stem and the leaves (A) indicate the diseased con- [illegible] case in India. *Albugo* belongs to the family [illegible]

Structure. The mycelia ramify through the intercellular spaces of the host plant and branch profusely. The hyphae are unseptate and multinucleate. Here and there they send globular or button-like haustoria (B) into the living cells of the host to absorb food from them.



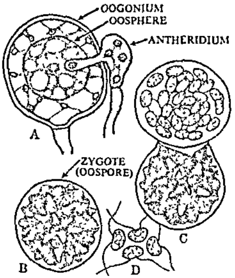
[illegible] separating the sporangia); D, germination of a sporangium—*A*, sporangium dividing; *B*, zoospores escaping; *C*, biciliate zoospores swimming; and *D*, a zoospore germinating.

Reproduction. *Albugo* reproduces both asexually and sexually.

Asexual Reproduction (FIG. 64C). The hyphae grow luxuriantly at certain points below the epidermis. They form erect, branched or unbranched, club-shaped, multinucleate sporangiophores in clusters. The latter begin to cut off spherical multinucleate **sporangia** in chains from their tips. The sporangia are separated from one another by short necks made of gelatin. The epidermis soon gets ruptured as a result of internal pressure exerted by the increasing number of sporangia which then appear on the surface as a white powdery mass. The sporangia are now carried by the wind to other plants. The protoplasmic contents of each sporangium (D) divide to form a few (4 or 8 or more) kidney-shaped **zoospores**, each with two lateral

cilia. The sporangium bursts and the zoospores escape. They swim about for some time in water that collects on the surface of the host plant. They soon lose their cilia, cover themselves with a wall and come to rest. Later they germinate by producing a germ tube which enters the host through a stoma. Sometimes a sporangium germinates directly without the intervention of the zoospores.

Sexual Reproduction (FIG. 65). Later in the season the hyphae produce separately male and female gametangia within the intercellular space of the host (A). To form the female gametangium or oogonium a hypha swells at the tip and becomes spherical. A septum appears at the base. The oogonium is multinucleate, and its cytoplasm becomes differentiated into two distinct zones: a central zone called the ooplasm which is the egg or oosphere, and a peripheral zone called the periplasm. The central zone is a dense mass of cytoplasm with an egg-nucleus in it (other nuclei of this zone usually degenerate); while the peripheral zone is lighter and multinucleate. To form the male gametangium or antheridium a hypha close to the oogonium swells at the tip and becomes more or less club-shaped. It is cut off at the base by a septum. The antheridium is multinucleate. Soon it comes in contact with the oogonium and produces a *fertilization tube* which penetrates through the oogonial wall and the periplasm and goes deep into the oosphere. One or more male nuclei are set free from this tube but only one of them fuses with the egg-nucleus. If more egg-nuclei be present all of them may be fertilized. Thus fertilization is effected. The zygote (oospore; *B*) formed thereby clothes itself with a thick wall, the periplasm taking part in its formation. The zygote is set free only after the decay of the host tissue. It undergoes a period of rest and then it produces numerous (over 100) zoospores. The zygote bursts and the zoospores escape into a vesicle (zoosporangium; *C*). The vesicle dissolves and the zoospores, each with two lateral cilia, are set free to swim about in water (*D*). The zoospore germinates under appropriate conditions by producing a germ tube.



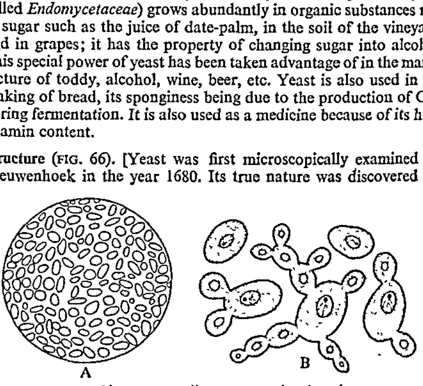
Albugo. FIG. 65. *A*, fertilization; *B*, zygote (oospore); *C*, germination of zygote—zoospores escaping into a vesicle; *D*, biciliate zoospores after escape.

CLASS III | ASCOMYCETES or sac fungi | 25,000 sp.

1. *SACCHAROMYCES* (*40 sp.*)

Occurrence. Yeast (*Saccharomyces*—family *Saccharomycetaceae*, no called *Endomycetaceae*) grows abundantly in organic substances ric in sugar such as the juice of date-palm, in the soil of the vineyarc and in grapes; it has the property of changing sugar into alcoho This special power of yeast has been taken advantage of in the manu facture of toddy, alcohol, wine, beer, etc. Yeast is also used in th making of bread, its sponginess being due to the production of CC during fermentation. It is also used as a medicine because of its hig vitamin content.

Structure (FIG. 66). [Yeast was first microscopically examined b Leeuwenhoek in the year 1680. Its true nature was discovered b



Yeast. FIG. 66. *A*, yeast cells as seen under the microscope; *B*, budding or gemmation.

Schwann in Germany as late as 1836.] Its structure is very simple. A single cell represents the whole body of the plant. It is very minute in size and looks like a pin-head under the microscope (*A*). Each cell is oval or almost spherical, provided with a distinct cell-wall, possibly made of *chitin*, and contains a mass of cytoplasm and a single nucleus. The nucleus contains a large vacuole (*C*), and this nuclear vacuole is a peculiarity in yeast. In the vacuole lies the nuclear reticulum with a nucleolus, and a centrosome on one side. Embedded in the cytoplasm there are granules of glycogen, several oil-globules, and also protein compounds.

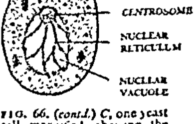


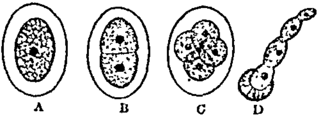
FIG. 66. (*contd.*) *C*, one yeast cell magnified showing the nuclear vacuole.

Reproduction. This takes place commonly by two methods, viz. vegetative and asexual. Sexual reproduction takes place only in a few species.

Vegetative Reproduction (*B*). This takes place by the process of budding under normal conditions when the yeast cells grow in sugar solution. As they grow there two changes are noticed —one in the yeast cells and the other in the sugar solution. The former change is the *budding* of yeast cells leading to vegetative reproduction, and the latter change is the *alcoholic fermentation* (see p. 456) leading to the breakdown of sugar into alcohol and carbon dioxide. In the process of budding each cell gives rise to one or more tiny outgrowths which gradually increase in size and are ultimately cut off from the mother cell; these then lead a separate existence. The nucleus divides amitotically and one passes on to each outgrowth. This method of reproduction is known as vegetative budding or gemmation (*gemma*, a bud; pl. gemmae). The budding may be repeated resulting in the formation of one or more chains and even sub-chains of bead-like cells; these cells ultimately separate from one another into individual one-celled yeast plants.

Asexual Reproduction (FIG. 67*A-C*). Under unfavourable conditions, particularly when food supply is scanty or exhausted, the yeast cell becomes larger and behaves as a sporangium. It is then called an ascus. When there is an abundance of oxygen the nucleus of the

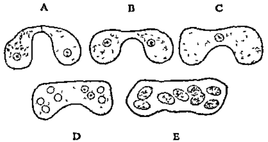
Yeast. FIG. 67. *A-C*, formation of ascus and ascospores; *D*, an ascospore germinating.



ascus divides into four. Protoplasm collects round each nucleus and thus four spores, called ascospores, are formed, each provided with a firm wall. Instead of four spores, sometimes two or eight may be formed. These are the resting spores, and can withstand unfavourable conditions of life. The wall of the ascus ruptures, and the spores are blown about by the wind. When they get a suitable medium they germinate and reproduce by the process of budding (*D*) or they take to conjugation to produce a zygote which *by budding* produces vegetative cells or directly becomes an ascus again. In the light of recent research it may be said that this method is really parthenogenetic and not asexual.

Sexual Reproduction (FIG. 68). Under unfavourable conditions some species of yeast also reproduce sexually by conjugation. In the

process of conjugation two adjacent cells send out short protuberances which unite with each other. The two nuclei then pass on to the conjugating tube and fuse with each other. The zygote (ascus) thus formed divides to produce eight nuclei. Each nucleus clothes itself with a wall, enlarges and becomes known as the ascospore.



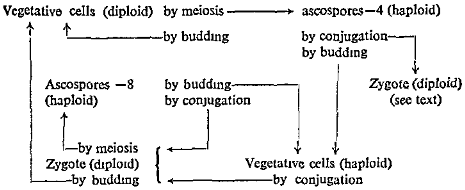
Yeast. FIG. 68. Conjugation of yeast cells and formation of ascospores.

The ascospore germinates by budding or sometimes two ascospores conjugate in pairs at once or later to give rise to a zygote. The zygote may produce vegetative cells *by budding* or may directly behave as an ascus to produce ascospores.

Alcoholic Fermentation. When the yeast cells grow in sugar solution, as in date-palm juice, palmyra-palm juice or grape juice, they set up fermentation (see p. 313) in it under the action of the enzyme *zymase complex*. Sugar is decomposed, and alcohol and carbon dioxide are the chief products formed. Carbon dioxide escapes, and often gives rise to frothing on the surface of the solution. When oxygen is abundantly supplied comparatively little alcohol is formed, but when the supply of oxygen is cut off alcohol is produced more freely. The following chemical change takes place in sugar:

$$C_6H_{12}O_6+\text{Zymase} = 2C_2H_5OH+2CO_2+\text{Zymase}+\text{Energy}$$
$$(\text{sugar} \ +\text{zymase} = \text{alcohol} \ +\text{carbon dioxide}+\text{zymase} \ +\text{energy})$$

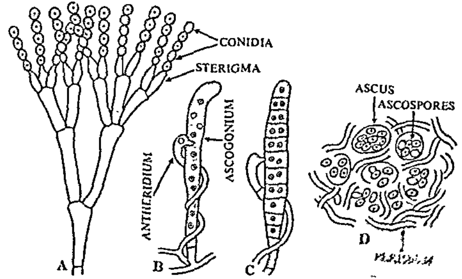
Sexual Behaviour and Life-history. Sexuality in yeast is rather peculiar and unique with haploid and diploid stages without any system and regularity. Vegetative cells may be diploid or they may be haploid, while ascospores are of course always haploid. It has been observed that there may be sexual reproduction (conjugation) between two haploid vegetative cells or between two ascospores; it is also not uncommon to find conjugation taking place between a haploid vegetative cell and an ascospore. The result of conjugation in any case is a zygote which presumably is diploid. The zygote gives rise to diploid vegetative cells by *budding* or it gives rise to ascospores (usually 8 in number) *by meiosis*. The ascospores produce haploid vegetative cells *by budding* or they *conjugate* in pairs to form a zygote. The diploid cells in their turn multiply in number *by budding* or they form ascospores (usually 4 in number) *by meiosis*, which produce haploid vegetative cells *by budding* or they conjugate in pairs to form a zygote. The life-cycle based on the above facts, as shown by Guilliermond in 1940, may be represented as follows:



Yeast cells are very rich in digestible compounds, specially proteins, fats, carbohydrates, etc., and also enzymes and vitamins, and as such their value as food is considerable. They are purified, dried at about 125°C, and sold in the market as yeastvite

2-3. *PENICILLIUM* (*137 sp.*) & *ASPERGILLUS* (*78 sp.*)

Penicillium (FIG. 69), commonly called blue mould, and *Aspergillus* (FIG. 70), commonly called green mould, are the two important genera of the family *Aspergillaceae*. They commonly grow on bread, vegetables, fruits, jams, leather, shoes, etc., and are mostly saprophytic in habit; a few, however, are parasitic upon animals. *Aspergillus* is used for various fermentation processes, and *Penicillium notatum* is the source of penicillin (an antibiotic).



Penicillium. FIG. 69. *A*, branched conidiophore ending in sterigmata with conidia in chains (penicillus); *B*, sex organs: antheridium and ascogonium; *C*, ascogonium with binucleate cells; *D*, [illegible]

Structure. The mycelium consists of an [illegible]

a fine white powder which can be easily brushed off. Common hosts of *Erysiphe* are cucurbits, cereals, some grasses, pea, bean, rose and numerous other plants. In India *Erysiphe polygoni* is common on pea and some other leguminous plants, and *E. graminis* on barley and some other cereals. The mycelium of the fungus consists of a network of colourless septate hyphae (*A*) which here and there send haustoria into the epidermis, and produce on the surface of the leaf a large number of simple erect conidiophores, each cutting off from the top downwards a chain of oval conidia, having the appearance of a powdery coating. The fungus multiplies rapidly by conidia.

Later with the cessation of conidia-formation the fungus produces uninucleate sex organs—ascogonium (female) and antheridium (male). The latter is more slender than the former. They develop side by side at the tips of hyphae pressing together closely (*B*). The male nucleus enters the ascogonium through a perforation made in its wall and pairs with the female nucleus of the ascogonium (*C*). It is now generally agreed that karyogamy (see p. 439) takes place in the young ascus mother cell. After this the ascogonium forms into a row of cells; the penultimate cell of this row produces ascogenous hyphae which then form asci, usually 2-8, within a closed ascocarp called cleistothecium (*D*). From the stalk-cells of the ascogonium and the antheridium sterile hyphae arise forming a sheath of the ascocarp. From the sheath-cells peculiar hooked branched bulbous or simple appendages develop around the ascocarp. These are important diagnostic characters. The ascocarps appear as white, reddish, brownish and finally black dots on the leaf. The ascus commonly bears 8 ascospores, sometimes less (2-6) in some species. The ascospores are liberated after the bursting of the ascocarp and the ascus (*E*).

The source of infection may be the dormant mycelium in the seed or the ascocarp remaining in the soil. *Control.* (*a*) Seeds may be soaked in hot water (50°C.) for about 10 minutes; (*b*) the plants may be dusted with fine sulphur dust.

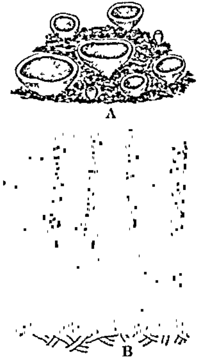
5. *PEZIZA* (*150 sp.*)

Peziza (FIG. 72) is a cup fungus; it is characteristically cup- or saucer-shaped and commonly varies in sizes from 1-4 cm. in diameter; some may be smaller or bigger. The cups are sometimes irregular and often contorted. *Peziza* belongs to the family *Pezizaceae*, and is saprophytic in nature. It is found growing abundantly during the rainy season on heaps of semi-decomposed cowdung, decaying wood and in soil heavily manured or rich in humus.

The hyphae are much branched and grow extensively penetrating into the substratum. The interwoven hyphae are massed together forming the aerial, fleshy, cup-shaped reproductive or fruiting body

known as the apothecium (see p. 440). The apothecium may be variously coloured, but often brownish, particularly on the inner surface, and is commonly sessile or short-stalked.

The inner wall of the apothecium is lined with a continuous layer (hymenium) consisting of countless numbers of asci intermixed with slender sterile hyphae—the paraphyses. Each ascus is a cylindrical body and contains 8 distinct ascospores which are arranged obliquely in a row. The ascospores, when mature, are liberated from the ascus through a terminal pore. Under suitable conditions and in an appropriate medium they germinate producing new mycelia.



Peziza FIG. 72. A, fruit bodies or cups (apothecia); B, a portion of apothecium (in section) showing asci (*A*) with ascospores and paraphyses (*P*).

Sexuality. There are no sexual organs in *Peziza* but in a few species a nuclear fusion of two vegetative hyphal cells has been observed. Thus prior to the formation of the apothecium nuclei of certain hyphal cells fuse in pairs indicating reduction of sexuality. These cells then give rise to the ascogenous hyphae from which asci are subsequently formed. If this is true the nucleus of the young ascus must be diploid. Then by three successive divisions, the first being reductional, 8 ascospores are formed in the ascus. The wall of the apothecium and the paraphyses are formed from vegetative hyphae.

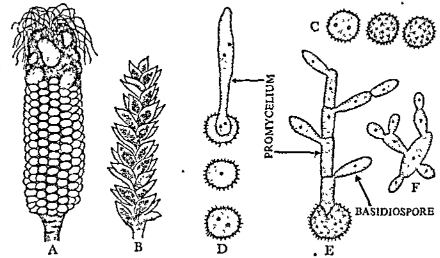
CLASS IV | BASIDIOMYCETES or club fungi | 23,000 sp.

1. *USTILAGO* (*300 sp.*)

Ustilago (family *Ustilaginaceae*) belongs to the order Ustilaginales or smuts which number about 700 species.

Ustilago or smut (FIG. 73) is a parasitic fungus commonly attacking members of *Gramineae*. It may also grow as a saprophyte in the soil rich in organic material. Some of the crops commonly attacked by *Ustilago* are maize, wheat, barley, oat, rice, sugarcane, etc. The damaging effect of corn-smut by *U. zeae* on maize (*A*), of oat-smut by *U. avenae* on oat, of loose-smut by *U. tritici* on wheat (*B*), etc., is often immense, and the total loss on this account is often tremendous.

The plants are generally infected when they are young. The mycelia may be local or widespread in the body of the host, and are sparsely septate. The hyphae ramify through the intercellular spaces, producing here and there some haustoria in some species, which penetrate into the living cells of the host to absorb food material from them. As a consequence the host plant becomes stunted in growth. The fungus tends to grow towards the meristematic regions, drying off from the older parts. When the flowering stage of the host plant



is attained the hyphae pass on to the flowers, particularly to the ovaries, and form there black soot-like masses of spores, and hence the name 'smut'. The spores are called **teleutospores** (or chlamydospores; *C*). They are formed in countless numbers and are thick-walled. The ovaries often become much swollen and always eventually distorted and destroyed. The primary mycelia formed from basidiospores (as described below) have at first uninucleate cells and are of limited growth. But soon two hyphae of opposite strains (+ and −) or two basidiospores (+ and −) or two budding cells (+ and −) fuse but no karyogamy, i.e. fusion of nuclei, takes place; the nuclei only pair. The secondary mycelia with binucleate cells (dikaryotic condition) then grow vigorously and spread throughout the body of the host, finally producing teleutospores. Clamp connexion (see FIG. 52) is common in *Ustilago*. The spores fall to the ground and remain there in dormant condition till the next spring. Rarely they germinate immediately after they are shed. Commonly the teleutospores do not directly infect a plant. They germinate in

the soil by producing a short filament, called promycelium (or basidium; *D*), which consists of 3 or 4 uninucleate cells. From each cell one or more thin-walled elongated basidiospores (also called sporidia) are formed by the process of budding (*E*). These basidiospores infect their own hosts by producing a germ tube which usually enters through a stoma. In some species, as in *U. Tritici*, the cells of the promycelium directly grow into hyphae without the formation of basidiospores. The mycelium also often remains dormant in the seed and eventually grows.

Mycelia and young teleutospores are binucleate (*D, bottom*). When the latter mature, nuclear fusion (karyogamy) takes place in them (*D, middle*). This is the diploid condition of the fungus. The diploid nucleus undergoes reduction division while the promycelium is being formed (*D, top*), and each haploid nucleus divides and one passes on to a basidiospore. More basidiospores may be formed from it by budding before or after shedding from the promycelium (*E* & *F*); the nuclei also correspondingly divide to supply one to each basidiospore.

Control. (1) Rotation of crops in the case of maize. (2) Hot water treatment of grains in the case of wheat, and then drying them under strong sun. (3) Spraying the grains with equal parts of commercial formalin and water in the case of oats, or dusting them with copper carbonate powder. (4) Cross-breeding with types resistant or immune to smut; this is possibly the best method.

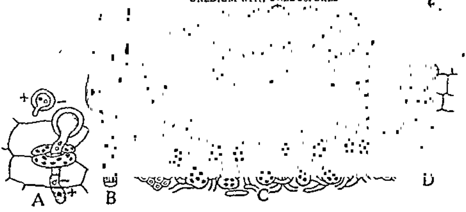
2. *PUCCINIA* (*700 sp.*)

Puccinia (family *Pucciniaceae*) belongs to the order Uredinales or rusts which are destructive parasites and number about 4,600 species. *Puccinia* species may be *heteroecious* requiring two distinct hosts to complete their life-cycle, or *autoecious* requiring only a single host to complete the entire life-cycle. Species of *Puccinia* attack a variety of host plants, particularly members of *Graminaceae*. *Puccinia graminis*, commonly known as the 'black rust' of wheat, is a *heteroecious* species attacking wheat plants and common barberry plants in rotation. This species is further polymorphic bearing different kinds of spores and spore-structures on wheat and barberry.

Life-history of *Puccinia graminis*. This species is a virulent parasite. It attacks wheat plants and often very seriously diseases them. The disease sometimes breaks out in an epidemic form and causes very heavy damage to the crop, resulting in great economic loss. It also attacks barley, oats and rye.

Stages on Wheat Plant. (*a*) Uredium and Uredospores (FIG. 74). In late spring or early summer the spores (aeciospores) carried by the wind from barberry to wheat germinate on the latter, each produc-

ing a germ tube through a stoma (*A*). Within 10-12 days of infection reddish-brown streaks appear on the stem, leaf-sheath and

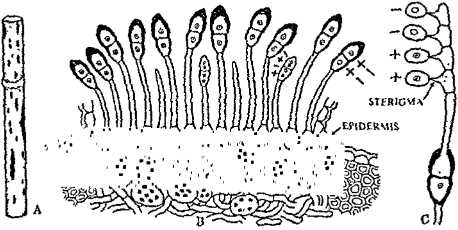


hyphae; *D*, germination of a uredospore on wheat plant again.

leaf (*B*) indicating the diseased condition of the plant. A section through the infected part shows a mass of mycelia ramifying through the intercellular spaces, penetrating here and there into the living cells of the host to absorb food from them, and on the surface a number of spore-clusters known as uredia (or uredosori). The hyphae of the mycelium are septate and the cells binucleate (+ and —). The uredia, as they grow, break through the epidermis and appear on the surface as reddish-brown streaks (*C*). The uredium bears numerous slender hyphae projecting outwards, each ending in a one-celled, rough-walled, brownish or reddish, binucleate (+ and —) spore called the uredospore. This stage is known as the 'red rust' of wheat. The spores, when mature, are blown about by the wind over a wide area, and they directly infect other wheat plants (*D*). The disease may thus appear in an epidemic form, destroying the whole or major part of the crop. The uredospores may be produced successively throughout the summer infecting the wheat plants each time. Ordinarily these spores cannot stand a very severe winter.

(*b*) Telium and Teliospores (FIG. 75). Later, i.e. in late summer the mycelia still existing in the wheat plant after the formation of the uredospores grow and mass together below the epidermis to give rise to black spots or streaks here and there on the stem (*A*), leaf-sheath and leaf. Each such spot or streak is a sorus called telium. The telium produces a large number of slender stalks, each ending in a black or dark-brown, elongated, two-celled, heavy-walled spore called the teliospore (*B*). This stage is the 'black rust' of wheat.

The teliospores are resting spores and help the fungus to tide over the severe conditions of winter. Each cell of the young teliospore is



Puccinia. FIG. 75. *A*, a wheat stem infected showing telia; *B*, a telium (in section) showing young binucleate teliospores (+ and −) and mature uninucleate teliospores (+ −) and also the infecting hyphae; *C*, germination of a teliospore (on old dry wheat plant or in the soil) *producing four basidiospores (uninucleate, + or −)*, each on a short sterigma.

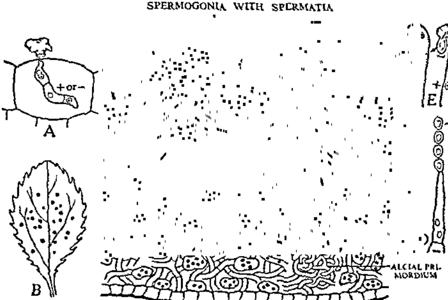
binucleate (+ and −) but soon the two nuclei fuse together (a reduced form of the sexual act), and the mature teliospore has two uninucleate cells (+ −). The spores, evidently diploid, remain dormant *on the wheat plant or in the soil till the following spring. They* do not infect the wheat plant again.

(c) Basidiospores. One or both cells of the teliospore germinate independently (*C*), each producing a slender elongated hypha called the basidium which consists of four terminal cells. Each cell produces a short *slender stalk called* the sterigma. Its end [illegible] and [illegible] iospore. The diploid nucleus of the [illegible] division, and the basidial cells and [illegible] hey are uninucleate and are of opposite *strains (two + and two −); Puccinia* is thus [illegible]. The basidiospores do not infect the wheat plant. They are blown about by the wind and incidentally many of them are [illegible] over to the barberry (*Berberis vulgaris*) bush where further [illegible] appear in continuation of its life-cycle.

Stages on Barberry Plant. (d) Spermogonium and Spermatia (FIG. [illegible]). The basidiospore germinates on the [illegible] by producing a [illegible]

Nomenclature. Uredium, uredosorus [illegible] or urediniospore. Telium or teleutosorus [illegible] teleutospore [illegible] mogonium, pycnium or pycnidium [illegible] Aecium or aecidium [illegible]

germ tube which enters the leaf through the cuticle (*A*). The mycelia grow extensively in the leaf-tissue and soon mass together beneath the epidermis (usually upper) forming in about 7-10 days of infection slightly raised yellowish or reddish spots, called spermogonia (or pycnia), on the leaf-surface (*B*). The cells of the mycelium as well as those of the spermogonium are uninucleate, either of +strain or of −strain, produced correspondingly from a +basidiospore or from a −basidiospore. In section the spermogonium is more or less flask-shaped (*C*). Its inner wall is lined with numerous fine hyphae (spermatial hyphae) which successively cut

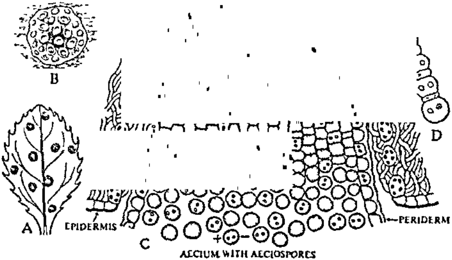


Puccinia. FIG. 76. *A*, germination of a basidiospore (uninucleate) on barberry leaf through the cuticle; *B*, barberry leaf infected showing sper- [illegible]

off from their ends very minute uninucleate cells called spermatia (or pycnospores; *D*). Several sterile hyphae called periphyses also [illegible] are exuded through the ostiole in a drop of sweet fluid. The sweet fluid attracts insects which carry the spermatia from one spermogonium to another which may be of the opposite strain. The spermatia come in contact with the receptive hyphae of the opposite strain and

their contents pass into them but no nuclear fusion takes place (*E*). The receptive hyphae, now with binucleate cells, extend to the *aecial primordium* formed near the lower epidermis from an interwoven mass of primary hyphae which have already penetrated the entire leaf-area. Some of the periphyses also may behave as receptive hyphae. There is also evidence that a + spermatium may unite with a − spermatium, giving rise to hyphae with binucleate (+ and −) cells. The receptive hyphae with binucleate cells eventually form the basal cells of the aecium (FIG. 77*C*).

(*e*) Aecium and Aeciospores (FIG. 77). The elongated binucleate basal cells of the aecium now give rise to clusters of comparatively



large cup-like blisters called aecia or cluster-cups on the lower surface of the leaf (*A-B*). As the aecium grows it breaks out of the epidermis (*C*). The basal cells begin to cut off from the bottom chains of binucleate cells which immediately divide producing large, orange or yellow cells (spores) called aeciospores and small sterile cells in an alternating manner (*D*); the latter soon disintegrate. Aeciospores are the first *binucleate spores* to appear in the life-cycle of the fungus. A protective layer called the peridium also develops from the basal cells of the aecium. Soon the peridium bursts and the spores are liberated. These are shed in late spring and early summer, and are blown about by the wind. If they happen to fall upon the wheat plant they infect it (FIG. 74*A*), and the life-cycle is repeated.

Sexuality, Diplophase and Haplophase. Sexuality in *Puccinia* is reduced to the fusion of two nuclei in the young teliospore. Diplophase (binucleate condition) begins with the cells of the receptive hyphae after spermatization (FIG. 76*E*) and continues through aecium and aeciospores on barberry and later on wheat through infecting mycelia, uredium, uredospores and finally young teliospores (where actual fusion of nuclei takes place). The haplophase (uninucleate condition) begins with the mature teliospores on wheat and continues on barberry through germinating basidiospores, infecting mycelia and finally spermogonium and spermatia. *Puccinia* is heterothallic, the basidiospores being distinctly of two opposite strains (+ and −). It should also be noted that in the whole life-cycle of *Puccinia* the diploid ($2n$) condition is represented by the mature teliospores only.

Control. No special method has yet been discovered to prevent or radically cure the disease. Certain methods have, however, been devised to control its intensity. (1) Eradication of the barberry bush near a wheat field is a good established practice. (2) By cross-breeding with rust-resistant varieties it has been possible to evolve new types of wheat which are immune to the rust for some years at least and for a particular locality. (3) Elimination of cultivation of wheat in the hills during summer may reduce the spread of the disease to the plains through uredospores. (4) Cultivation of rust-resistant varieties.

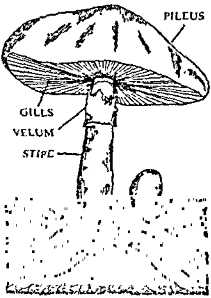
3. *AGARICUS* (*about 70 sp.*)

Agaricus (=*Psalliota*), commonly called mushroom (when edible) or toadstool (when poisonous), is a fleshy saprophytic fungus. It grows on damp rotten logs of wood, trunks of trees, decaying organic matter, and in damp soil rich in organic substance. It belongs to the family *Agaricaceae* which has about 5,000 species. Other common genera of *Agaricaceae* are *Amanita*, *Lepiota*, *Coprinus*, *Marasmius*, etc.

Edible and Poisonous Forms. There are about 200 species of fleshy fungi that are edible; many more are non-edible, and about 12 species distinctly poisonous. All puff-balls are edible, particularly when they are young. Other common edible fungi are *Agaricus campestris* (=*Psalliota campestris*), *Morchella esculenta*, *Volvaria terastria*, *Lepiota mastoides*, etc. Certain species of *Amanita* which resemble edible *Agaricus* are extremely poisonous; these, however, are usually distinguished from the latter by their possession of a cup-like structure (called volva) at the base, which is wanting in *Agaricus*. Edible types cannot be easily distinguished from poisonous ones except by critical examination. Generally speaking, (1) most of the species having a bright colour are to be regarded as poisonous; (2) those bearing pink spores, and (3) those having a cup at the base are also poisonous; (4) a hot burning taste or acid flavour should as a rule be avoided; (5) those growing on the wood, and (6) those whose stem does not break easily, when touched, are non-edible; and (7) non-edible types do not generally grow in open sunny places.

Structure (FIG. 78). The mycelium consists of a much-branched mass

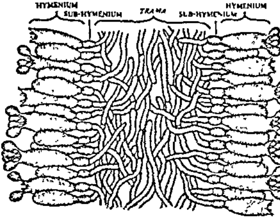
of hyphae which unite (anastomose) at their points of contact and form a network in the substratum in which they grow. The hyphae are septate and hyaline, and contain finely granular protoplasm with vacuoles, many nuclei and conspicuous oil-globules. The aerial portion of the fungus constitutes its main body and is the 'fructification' *or fruit-body of the plant. The fruit body, otherwise called basidio*carp (basidia-forming body) or sporophore (spore-producing body) consists of a fleshy stalk and an umbrella-like head borne on its top. The stalk and the head are composed of an interwoven mass of hyphae, and in sections they have the appearance of a tissue—a false tissue—known as pseudo-parenchyma. The stalk of the fungus is known as the stipe (a stem), and the expanded head or cap on its top is known as the pileus (a cap or hat). The pileus is more or less rounded and convex. *When young, the fructification* is spherical in shape (button stage) and is completely enveloped by a thin membranous covering, called the veil or velum. With the growth of the fruit-body, specially the pileus, the velum is ruptured, the remnants of which remain surrounding the stipe as a ring (annulus). Ultimately the pileus spreads in an umbrella-like fashion on the top of the stipe. From the undersurface of the pileus suspend a very large number of thin vertical plate-like structures, extending from the stipe to the margin of the pileus; these are known as the gills or lamellae. They vary in number from 300 to 600 for each fructification. Each gill bears innumerable spores on both the surfaces.



Agaricus. FIG. 78. Two plants, young and old, with ramifying mycelia.

Reproduction (FIGS. 79-80). This takes place by the asexual method only. The spores are known in this case as the basidiospores, and are borne by the gills on both surfaces. A gill in section shows three distinct portions: trama, sub-hymenium and hymenium. The trama is the central portion of the gill and consists of an interwoven mass (false tissue) of long slender hyphae. The hyphal cells of the trama curve outwards on either side of the gill and terminate in a layer of small rounded cells; this layer is the sub-hymenium. External to it lies the hymenium composed of a layer of club-shaped cells, called

basidia. Some of them bear spores; while others, the so-called paraphyses, are in reality immature basidia. Each basidium bears four basidiospores—in some cases two only—on short slender stalks,

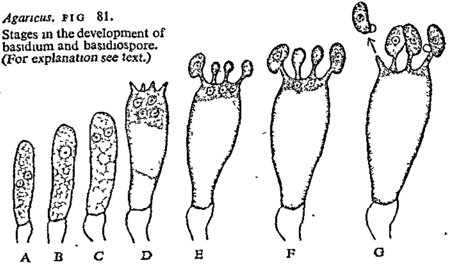


Agaricus.
FIG. 79.
A gill in section.

known as sterigmata (sing. sterigma). The basidiospores, when mature, fall off and germinate under favourable conditions.

Agaricus.
FIG. 80.
A portion of a gill in section.

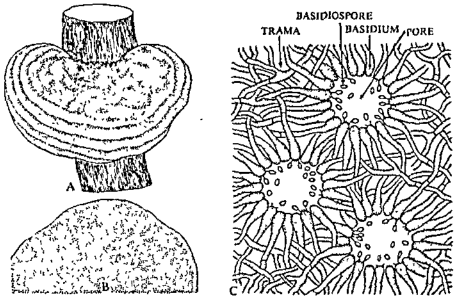
Agaricus. FIG 81.
Stages in the development of basidium and basidiospore. (For explanation see text.)



Development of Basidium and Basidiospore (FIG. 81). The basidium is at first binucleate (*A*). The two nuclei, each with *n* chromosomes, fuse to form the zygote nucleus (*B*). The latter, evidently provided with 2*n* chromosomes, undergoes reduction division giving rise to four daughter nuclei, each with *n* chromosomes (*C*-*D*). Slender projections or sterigmata—usually 4, sometimes 2 in number—are formed at the end of each basidium (*D*). Each sterigma swells at the end, and a nucleus migrates into it from the basidium (*E*). The swollen end-cell with a nucleus in it is the basidiospore (*F*). A small outgrowth, called hilum, is formed at the junction of the basidiospore and the sterigma. A drop of water accumulates on the hilum, and then the basidiospore together with the drop of water suddenly shoots off from the sterigma (*G*). This explosive mechanism is not, however, understood.

4. *POLYPORUS* (*about 500 sp.*)

Polyporus (FIG. 82), a pore fungus, belongs to the family *Polyporaceae* which has over 1,000 species. Other common genera of this family are *Polystichus*, *Fomes*, *Daedalea* and *Lenzites*. Many species of *Polyporus* grow as bracket or shelf fungi, either singly or in groups, on many forest trees, stumps and logs of wood, and are



Polyporus. FIG. 82. *A*, the fungus growing on a dead branch; *B*, lower surface of the fungus (a portion) showing pores; *C*, fruit body (in transection through the pore-tubes).

responsible for wood decay, sometimes causing heavy damage. This has necessitated the use of wood preservatives, particularly in the case of timber. *Polyporus* is commonly annual. The mycelia develop within and below the bark, and sooner or later form on it a more or less flat fruit body (*A*) called **basidiocarp** (basidia-bearing body) or **sporophore** (spore-bearing body). The fruit body is leathery,

corky or woody, and is whitish or slightly greyish or brownish in colour. The upper surface may be smooth, rough or warted, often undulating, and in some species distinctly striated, particularly towards the outer margin; while the lower surface is porous (*B*). The fruit body in section (*C*) is seen to consist of (*a*) a **context** which is the upper or outer fibrous part made of thick-walled hyphae; (*b*) a **trama** which is a loose mass of much-branched, septate and anastomosing hyphae; (*c*) a series of **pores** or **tubes** which extend from below the context to the lower surface; on the lower surface the pores appear as innumerable minute holes, practically covering it; and (*d*) a **hymenium** which is made of a distinct layer of basidia lining each pore. The **basidia** are club-shaped and slightly project into the pore. Each basidium bears four short slender **sterigmata**. Each sterigma forms a **basidiospore** at its end by abstriction. The basidiospores are discharged continually for some weeks into the pores through which they escape freely and are blown about by wind. The basidiospore shoots from the sterigma exactly in the same way as in *Agaricus* (see FIG. 81). An enormous quantity of basidiospores is produced by a fruit body. They germinate under favourable conditions.

It may be noted that the primary hyphae formed from the basidiospores have uninuceate (*monokaryotic*, + or −) cells; while the secondary hyphae have binucleate (*dikaryotic*, + and −) cells. The basidiospores (+ or −) germinate close together, and the hyphae freely anastomose with the result that the + or − nucleus of one primary hypha passes into another primary hypha of the opposite strain A dikaryon (see p. 439) is the result. The secondary hyphae that develop from dikaryotic hyphae have binucleate (*dikaryotic*, + and −) cells. The basidium which is the terminal cell of a secondary hypha is similarly binucleate (+ and −). One nucleus goes to a basidiospore which evidently is either + or −, finally giving rise to a + hypha or a − hypha.

CLASS V | DEUTEROMYCETES or fungi imperfecti . | over 24,000 sp.

1. *Helminthosporium* (175 sp.) belongs to the family *Dematiaceae*. *H. oryzae* (FIG. 83) is a parasitic fungus commonly attacking all parts of the rice plant, particularly the leaves as conspicuous brown leaf-spots and the ears which then become distorted and sterile. The disease is fairly common in Assam and Bengal, but only occasionally appears in other
spaces and penetr
of reproduction k
emerge in groups, mainly through the stomata, and ...
towards the top. The conidia are multiseptate, the septa varying in number from 5-10. The disease spreads under conditions of rains and cloudy weather. It is commonly a seed-borne disease. Control of the disease has not proved successful yet.

2. *Fusarium* (65 sp. and several varieties) belongs to the family *Tuberculariaceae*. Species of this genus are often very deceptive because of great variability of forms. Some of the common species of *Fusarium* causing wilt-diseases in India are *F. udum* attacking pigeon pea, and *F. vasinfectum* attacking cotton. Besides, the wilt-disease of linseed caused by *F. lini* and that of cabbage by *F. conglutinans* are also fairly common. Infection of the host plant takes place through tender roots. The mycelium penetrates into the vascular tissues. Black streaks are formed, which soon spread to the stem and the branches. The fungus remains restricted to the vascular tissues. The mycelium grows profusely within the vessels and plugs them. Wilting followed by death results. **Reproduction.** The fungus reproduces by macroconidia, microconidia and chlamydospores (see p. 439). Sclerotium formation is not also uncommon. **Macroconidia** (FIG. 84*A*) are long,

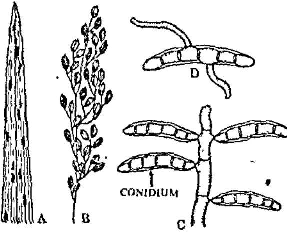


FIG. 83

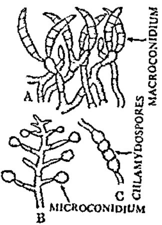


FIG. 84

[illegible]

of vegetative hyphae much like a mattress, covered with conidiophores on the surface of the host plant. **Microconidia** (FIG. 84*B*) are small, usually oval and unseptate or uniseptate. They are formed within the tissue, but on the surface of the plant they are held together in groups in a drop of liquid. **Chlamydospores** (FIG. 84*C*) are formed in chains within the tissue. The conidia and the spores, when shed, remain in the soil and are viable for long periods. Control of the disease has not been achieved yet by any direct treatment. *Long periods of rotation, however, have been found effective.*

Plant Pathology

A Short Historical Account. Work on plant pathology was initiated by Tillet whose experimental investigations on the bunt (stinking smut) of wheat elucidated the cause of the disease and its prevention. He published the results of his work in 1755, and was awarded the first prize offered by the Academy of Bordeaux. Provost's further work in Geneva in 1807 threw more light on the causative fungus (*Tilletia tritici*) and the effective treatment by copper sulphate. In the meantime Andrew Knight's work on wheat rust in 1804 established the fact that spores from barberry infect wheat plants. Plant pathology was actually founded as an important branch of study through the extensive work carried out by De Bary (1831-88) and Kuhne (1825-1910) from the middle of the 19th century. Butler (1874-1943), Imperial Mycologist in India (1905-19) and later Director of the Mycological Institute (1920-35), did valuable work on fungal diseases of plants. His *Fungi and Diseases in Plants* is specially notable.

Plant Diseases caused by Fungi and Bacteria. *Symptoms and Causes.* Many parasitic fungi, commonly called *pathogens*, attack several field crops, cultivated plants, ornamental plants and also wild plants, and cause various, often serious, diseases in them. The fungi plunder the food stored in the host plants, block the conducting tissues, destroy the affected cells and tissues, produce toxins (poisons) in them, and finally cause their death. The annual loss in agricultural crops on this account alone is very heavy. Some of the common diseases of useful and economic plants caused by fungi are as follows. The plant, as in the case of an animal, may suffer from one or more diseases at a time. (1) **Leaf Spot Disease.** This is a very common disease of a variety of plants. In this disease some areas of the leaf are infected, which then appear as brown, orange-red or blackish patches of different dimensions in different cases. The disease may spread from one part to another. Leaf spot diseases are caused by a number of fungi. Some common cases are: the late blight of potato caused by *Phytophthora*, leaf spot (dark-brown) of rice caused by *Helminthosporium* (the fungus also attacks and destroys the grains), 'tikka' disease (dark-brown spot) of groundnut caused by *Cercospora*. (2) **Rust Disease.** This is a serious disease of wheat and other cereals caused by *Puccinia*. The disease appears in the form of reddish, orange or black spots and streaks on the leaf, leaf-sheath and stem. (3) **Smut Disease.** This is [illegible], maize, oats and sugarcane [illegible] widespread. The fungus mainly attacks the stem, [illegible] the whole inflorescence. The infected parts turn black and all the grains are often totally destroyed, thus causing a heavy loss to the cultivators. (4) **Mildews.** These diseases appear on the leaves as whitish, yellowish or brownish spots and are caused by a number of fungi, e g. downy mildews of mustard, radish, cauliflower, cabbage, pea, *Sorghum*, potato, lettuce and grape caused by *Albugo* and others, and powdery mildews of rose, pea, bean, barley, apple and *Phlox*

caused by *Erysiphe* and others. (5) Rots. Root-rot, foot-rot (attack of the stem at the soil level) and stem-rot caused by *Pythium* and some other fungi are some of the common diseases of tobacco, cotton, papaw, jute, rozelle, ginger, etc. Red rot of sugarcane caused by *Colletotricum* is a very serious and destructive disease in India. (6) **Wilting Disease.** Seedlings or some soft parts of plants are sometimes attacked by a fungus called *Fusarium* and the infected parts wilt and dry up. Such a disease is fairly common in cotton, pigeon pea, etc. (7) **Damping-off Disease.** Seedlings growing in constantly wet seed-beds are attacked at the base (usually the hypocotyl) and they fall over. This disease is commonly caused by a fungus called

[illegible]

stem forming a depression, often with a raised margin, e.g. canker disease of *Citrus* (mainly lime and orange), rubber tree, apple tree, pigeon pea, etc. (9) **Bacterial Diseases.** Some of the plant diseases are also caused by parasitic bacteria, e.g. fire blight of apple and pear, ring disease of potato, wilt of potato, cucumber and water melon, canker of *citrus*, wi [illegible]

diseases are, [illegible]

In addition to the above many moulds damage vegetables, fruits and foods in storage, and also fabrics, paper, leather, etc.; similarly, wood-rotting fungi (e.g. *Fomes*) often do damage to timber.

Control. *Prevention and Check.* Considering the heavy economic loss [illegible] that proper and ade[illegible] control them as far as practicable. Some [illegible] ldely practised to destroy the causative fungi or keep them under check are as follows. (1) Spraying or dusting the affected plants with certain poisonous chemicals, called fungicides, e.g. copper sulphate, sulphur, sulphur-lime, quick-lime, etc., or a mixture of them. (2) Fumigation by sulphur dioxide gas. (3) Seed treatment—cautious application of hot water, formaldehyde or certain compounds of copper, [illegible] of mercury. (4) Soil sterilization by burning wood in the field or by [illegible]

[illegible]

disease-resistant varieties of plants. [illegible] some other crop in place of the existing one [illegible]

Antibiotics

Antibiotics [illegible]

possibly [illegible]

soil fungi, which have been found to check the growth of particular types of infective bacteria (germs) and even destroy them. Antibiotics are the miracle drugs of the modern times. They act like magic bullets shooting down the germs which have invaded the human body and caused infectious diseases, often of virulent nature, e.g. pneumonia, typhoid, diphtheria, tuberculosis, cholera, boils, abscesses, erysipelas, etc., and that too within a very short time. Within the last 15 years or so some 300 antibiotics have been isolated and studied at an almost incredible cost. Of these about 13 have an established therapeutic value in different bacterial diseases. The first antibiotic was an accidental discovery. For others which came in succession the persistent and painstaking labour, patience and perseverance, skill and cost involved in the examinations of several thousands of soil-samples, cultures and isolation of the bacteria present in them, study of their secretions and curative value, etc., are almost unimaginable. It is indeed a miracle that lay hidden in a spoonful of good earth for the benefit of mankind.

The first, best-
isolated by the la
from a blue-gree
has a powerful antibacterial action and is amazingly effective against certain types of bacteria, called Gram-positive bacteria, which cause some virulent diseases like scarlet fever, tonsilitis, sore throat, rheumatic fever, erysipelas, wound infections, abscesses, carbuncles, tetanus, pneumonia, meningitis, etc. Penicillin really acts like a shotgun on a wide range of its objectives. It has come into general use since 1943-4 when mass production first got under way.

Another antibiotic, called **streptomycin**, was isolated in 1944 by Waksman, a microbiologist, from a species of soil-bacteria, called *Streptomyces griseus*. It mainly attacks some of the Gram-positive

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ing next [illegible]
it into mice after infecting them with some disease germs (*Staphylococcus*, *Streptococcus* and *Pneumococcus*) and found to his great amazement that the mice were cured. That was the age of sulpha drugs, and this wonderful discovery lay unheeded for many years, possibly forgotten. Fleming, however, continued his research, and in February, 1941 he gave his first injection to a human patient,
a dy[illegible]
imm[illegible]
prep[illegible]
was similarly tried out again [illegible]
could, however, be foreseen, and soon some British and American pharmaceutical firms undertook to manufacture it on a large scale.

germs, particularly tubercle bacilli, and has proved to be very valuable against tuberculosis. A vigorous search for more antibiotics went on at this time, and soon another antibiotic, named **chloromycetin**, was discovered by Burkholder, a microbiologist, in 1947. It was isolated from *Streptomyces venezuelae*. It has a powerful action on a wide range of infectious bacteria—both Gram-positive and Gram-negative, and is very effective in severe types of dysentery, intestinal infections and whooping coughs. It has proved to be a magic drug in the treatment of typhoid fever caused by typhus bacilli. Next in the chain of antibiotics were **aureomycin** isolated in 1948 by Duggar, a botanist and a world authority on mushrooms, from *Streptomyces aureofaciens*, and terramycin isolated in 1950 or a little earlier from *Streptomyces rimosus* under the auspices of the Pfizer Company of Brooklyn, the world's largest producers of antibiotics. Both are yellowish powders, and are very effective on a wide range of disease germs, particularly on penicillin-resistant cases, cholera and some virus diseases. **Erythromycin**, another antibiotic, discovered by McGuire in 1952 from *Streptomyces erythreus*, has proved to be particularly effective on drug-resistant *Staphylococcus*. It is also remarkably active against whooping cough, diphtheria, large viruses, etc. Its range of action is very wide like penicillin.

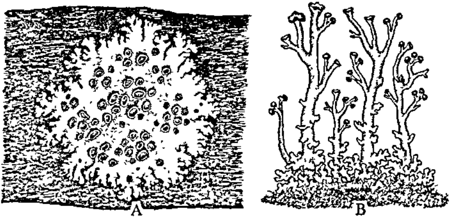
Gradually some more new and hitherto unknown soil bacteria have been discovered, and antibiotics manufactured and released to the market to relieve human sufferings. These wonder drugs have already saved and are still saving millions of human lives.

The latest, possibly not the last, in the series of antibiotics is **jawaharene** which was discovered in 1963 by Dr D. K. Roy at the Institute of Biochemistry and Experimental Medicine in Calcutta, from a species of *Aspergillus* growing on rotten potato tuber. This antibiotic has proved to be very active against various diseases such as pox, poliomyelitis, influenza, etc., and against ameobic dysentery, leukaemia (a deadly disease) and various forms of tumours.

Chapter 5 LICHENS

General Description. Lichens comprising 15,000 species form a large peculiar and interesting group of plants, being associations of certain algae and fungi, the latter constituting the greater part of the lichen body. They were first discovered by Tulasne in 1852, and a few years later De Bary studied in detail the two organisms in them.

The associations of different algae and fungi give rise to distinct species. Lichens commonly occur as greyish-green or bright-coloured incrustations, 1 to several cm. in diameter, on tree trunks, wooden posts, logs of wood, rocks, walls and ground, or sometimes hanging [illegible] of humidity and temperature, and may survive long periods of desiccation. They are very widely distributed in all regions. In lichens



Lichens. FIG. 85. *A*, a foliose lichen (*Parmelia*); *B*, fruticose lichen (*Cladonia*).

algae and fungi live together in intimate relationship. The two organisms are of mutual help to each other and lead a symbiotic life. The fungi absorb water and mineral matter and supply the same to the algae, while the latter in their turn prepare food and supply it to the fungi. Lichens are thus very good examples of symbiosis. If they are separated from their associations they lead a precarious life, more particularly the fungi.

Classification. Lichens may be classified into three principal groups: (*a*) crustose lichens forming hard granular crusts closely adhering to rocks, tree trunks and certain soils, e g. *Graphis* and *Lecanora*; they show very little differentiation between the upper surface and the lower; (*b*) foliose lichens (FIG. 85*A*) forming definite flattened leaf-like thalli with lobed margin adhering to walls, tree trunks, rocks [illegible] lower, and (*c*) fruticose lichens forming a much-branched [illegible] body which remains attached by the narrow basal portion only; the branches may be flat and ribbon-like or they may be slender and filamentous; such lichens may be standing erect, e.g. *Cladonia*

(FIG. 85*B*), or drooping from branches, e.g. old man's beard (*Usnea*; FIG. 86*A*).

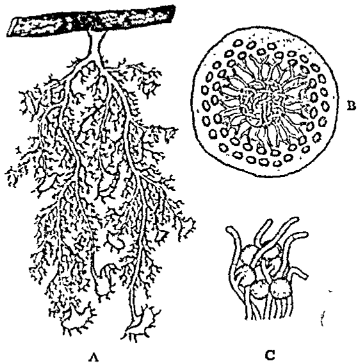


FIG. 86. *A*, a fruticose lichen (*Usnea*); *B*, a section through the thallus of *Usnea*; *C*, a soredium.

Thallus. The main framework of the thallus is made up of an interwoven mass of hyphae of a fungus, commonly an ascomycete (ascolichen) or in a few cases a basidiomycete (basidiolichen), enclosing a unicellular or filamentous type of blue-green or green alga. The types of the alga and the fungus associated in a lichen are always constant. In some lichens the algae remain scattered in the thallus and in others they occur in 1 or 2 layers. A section through the thallus (FIG. 87) of a foliose lichen shows a loose mass of hyphae in the central region—the so-called medulla and a compact mass in [illegible] algal cells (commonly called gonidia) held together in the meshes of the hyphae. In *Usnea*, a fruticose lichen, the thallus (FIG. 86*B*) seems to be differentiated into a central compact core of hyphae, a

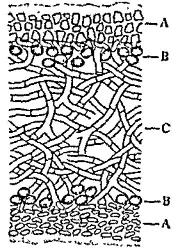
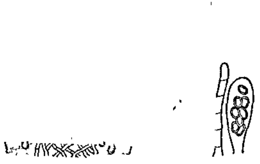


FIG. 87. A section through the thallus of a foliose lichen. *A*, cortex; *B*, gonidial layer; and *C*, medulla.

region of loosely interwoven hyphae, an algal region and externall another compact region.

Reproduction. Lichens reproduce themselves in a variety of ways (*a*) vegetative, (*b*) asexual and (*c*) sexual.

(*a*) **Vegetative Reproduction.** This takes place by tiny granula bodies known as **soredia**. Each soredium (FIG. 86*C*) is a little mas of alga of one or more cells wrapped up in a weft of fungal hyphae Soredia are sometimes produced in large numbers on the thallus lik a coating of dust particles, as in *Usnea* and *Cladonia*; these are ther blown about by wind. They germinate directly into new lichen thall or form new soredia. Sometimes the thallus becomes separated into



A B

FIG. 88.
A, a section through an apothecium; note the asci and the paraphyses;
B, an ascus and a paraphysis.

fragments. Each such fragment is seen to grow up to the size of the parent thallus. In *Usnea* the branches may be broken up by the wind into several fragments. Some of them at least get stuck to some branches of trees and grow up. Some lichens may form outgrowths (isidia) with both algal cells and fungal hyphae on the surface of the thallus. These outgrowths may be detached from the parent thallus and then they develop into new thalli.

[illegible]

or fructification is known as the **ascogonium** or **ascocarp**. In *Usnea* and many other ascolichens the ascocarp takes the shape of an open cup or saucer, very much like that of *Peziza*, known as the **apothecium**. Each apothecium (FIG. 88*A*) consists of an interwoven mass of hyphae with a surface layer of slender erect elongated cells known as the **hymenium**. The hymenium consists of a series of club-shaped cells—the asci—intermixed with a large number of sterile hyphae—the paraphyses. In each ascus usually eight ascospores develop but the number varies from 1 to 8 (FIG. 88*B*). Ascospores are liberated and those coming in contact with the right type of alga produce the lichen thallus. In some lichens, however, the ascogonium is a closed chamber, known as the **perithecium**, with an apical opening. The asci and the paraphyses develop in a layer on the inner wall of the peri-

thecium. Basidiolichens reproduce by basidiospores, as in *Agaricus*. [illegible]

The pycnospores develop in special receptacles or chambers known as **pycnidia** which externally appear as small black dots on the surface of the thallus, or as small protuberances on the margin of the thallus-lobe.

(*c*) **Sexual Reproduction.** This has been observed in a very few cases only, as in *Collema*. Male cells, called **spermatia**,[1] develop within a chamber known as the **spermogonium**. A number of spermogonia may be formed on the thallus. The inner wall of the spermogonium is lined with a layer of short slender branches—the *sterigmata*. Spermatia are formed from these branches by abstriction like conidia. They are very minute in size and cylindrical in form. The spermatia after they are liberated float in moisture on the thallus. The female organ *is a multicellular filament known as the* **archicarp**. *It consists* of a spirally coiled basal portion lying embedded in the thallus, known as the **carpogonium**, and an extended portion lying beyond the thallus, known as the **trichogyne**. The spermatia come in contact with the sticky protruding tip of the trichogyne, and their protoplast migrates into the trichogyne. After nuclear fusion the carpogonium enlarges and becomes converted into the ascogonium (apothecium). Ascogenous hyphae develop from the base of the carpogonium after fertilization, and these produce asci at their ends. The vegetative hyphae of the thallus simultaneously grow and form the investing tissue of the ascogonium.

Uses. Lichens growing on rocks disintegrate them to form soils, thus *preparing the ground first for mosses and subsequently for higher* plants. Lichens have a variety of uses. Some of them are a valuable source of food to wild animals, as reindeer moss (*Cladonia*) of the arctic tundra. In some countries lichens are fried for cattle food and to some extent also for human food. Some types are used as medicines. Some yield dyes. Litmus is prepared from certain lichens. Some species are used in cosmetics and in perfumes.

[1] The nature of spermatia is a disputed point. Although in some cases spermatia act as male cells, in others they have been found to act as spores (pycnospores) germinating independently.

Chapter 6 BRYOPHYTA

Classification of Bryophyta (23,525 sp.)

Class I Hepaticae or liverworts (8,550 sp). **Order 1.** Marchantiales (400 sp.), e.g. *Riccia*, and *Marchantia* (thalloid liverworts). **Order 2.** Jungermanniales (8,050 sp.): (*a*) anacrogynous, e g. *Pellia*, and (*b*) acrogynous, e g. *Porella*; in the former the archegonia always develop behind the apical cell (never from the apical itself) and the gametophytes are thalloid, while in the latter the archegonia always develop from the segments of the apical cell and later from the apical cell itself and the gametophytes are leafy. The latter far outnumber the former.

Class II Anthocerotae or horned liverworts (300 sp). **Order 1.** Anthocerotales (only order), e g. *Anthoceros* (gametophyte simple and thalloid but sporophyte complex).

Class III Musci or mosses (14,975 sp.). **Order 1.** Sphagnales or bog mosses (350 sp.), e.g *Sphagnum*. **Order 2.** Andreaeales (125 sp.), e.g. *Andreaea*. **Order 3.** Bryales or true mosses (14,500 sp), e g. *Funaria, Polytrichum, Barbula* and *Dicranella* (gametophyte distinctly leafy and sporophyte very complex).

Origin and Evolution of Bryophyta. Bryophyta do occupy, no doubt, an intermediate position between the higher algae and the lower pteridophyta but their ancestors and descendants are not known. It is, however, most likely that bryophytes have evolved from some algal stock, possibly Ulotricales but because of the missing links between the higher algae and the lower bryophytes the actual position in regard to the origin of the latter cannot be ascertained. Having originated from some aquatic ancestor the bryophytes were pioneers in establishing themselves on land. This was a very important early event in the progressive evolution of plants under land conditions. Having established themselves on land they followed their own independent course of development (evolution), culminating in an individualistic group without giving rise to higher forms. Among bryophytes the liverworts are more primitive than the mosses, and the latter may have been derived from the former. According to another view the bryophytes have diverged from pteridophytes; later they followed an independent line of evolution ending in a blind alley without giving rise to higher forms. Bryophyta show an advance over algae by the development of archegonia, multicellular antheridia, and a distinct alternation of generations. By the same characters they are a near approach to the pteridophytes but the absence of vascular tissues and the dependence of the sporophyte upon the gametophyte have prevented them from coming to the pteridophytic level. The mode of fertilization by ciliate antherozoids through an aquatic medium has persisted from algae to bryophytes to pteridophytes and to certain lower gymnosperms; this may indicate a connecting link between these groups.

Development of the Sporophyte. The sporophyte is a distinct structure which has evolved from the zygote, and is diploid (with $2n$ chromosomes) and reproduces asexually by spores. It is the product of sexual reproduction and represents the stage between fertilization and subsequent meiosis (reduction division). In most green

algae the zygote represents only a passing diploid ($2n$) phase without giving rise to a sporophyte. In them the zygote is only a resting body with protective covering to tide over unfavourable conditions. The

[illegible]

appearance it passed through successive developmental changes towards greater and greater complexities, and has in due course established itself as the main plant body; from ferns onwards all plants are sporophytes. Certain factors seem to be connected with the gradual development of the sporophyte: immediate germination of the zygote without any rest, prolongation of the vegetative period and delay in meiosis leading to the formation of spores, alternation of generations, land habit, facility of dispersion of spores by wind, sterilization of sporogenous tissue for other functions, and segregation of the spore-producing region from the vegetative region.

The sporophyte, to start with, is a simple structure lying embedded in the gametophytic thallus as a parasitic body, with nearly all its cells producing spores. This is the case of *Riccia*. A more complex type of sporophyte is formed in *Marchantia*. Here the sporophyte grows from the ray of the female receptacle and is already differentiated into a foot, seta and a capsule. In it some of the potentially sporogenous cells give rise to sterile cells—the elaters, and others to spores. Thus a partial sterilization is evident. Besides, the capsule of *Marchantia*, unlike that of *Riccia*, dehisces to liberate the spores for their dispersal. In *Anthoceros* the sporophyte has reached a high degree of complexity in many respects: relatively large size, continued growth in length by a basal meristem, extensive sterilization of the capsule leading to the development of the central axis—the columella, development of chlorophyllous cells and also other cellular differentiation in response to division of labour as a definite move towards an independent existence, partial sterilization of the sporogenous tissue leading to elaters and spores alternately, and all this on a simple primitive type of gametophyte, i e. thallus. In it the mechanism of liberation of spores by dehiscence of the capsule into two valves is also very efficient. In moss the sporophyte has reached a high degree of specialization, on a highly developed gametophyte. In this plant the extensive amount of sterilization has resulted in an enlarged seta and a very complex capsule. The sporophyte of moss is not still quite an independent plant. *Anthoceros* and moss have, however, followed two independent lines of evolution. At the next higher stage, that is, in fern, the table is turned; the sporophyte has

[illegible]

plant, has elaborately developed roots, stem (often branched) and

Chapter 6 BRYOPHYTA

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Class II Anthocerotae or horned liverworts (300 sp.). **Order 1.** Anthocerotales (only order), e g. *Anthoceros* (gametophyte simple and thalloid but sporophyte complex).

Class III Musci or mosses (14,975 sp). **Order 1.** Sphagnales or bog mosses (350 sp.), e g. *Sphagnum*. **Order 2** Andreaeales (125 sp), e.g. *Andreaea*. **Order 3.** Bryales or true mosses (14,500 sp.), e g. *Funaria*, *Polytrichum*, *Barbula* and *Dicranella* (gametophyte distinctly leafy and sporophyte very complex).

Origin and Evolution of Bryophyta. Bryophyta do occupy, no doubt, an intermediate position between the higher algae and the lower pteridophyta but their ancestors and descendants are not known. It is, however, most likely that bryophytes have evolved from some algal stock, possibly Ulotricales but because of the missing links between the higher algae and the lower bryophytes the actual position in regard to the origin of the latter cannot be ascertained. Having originated from some aquatic ancestor the bryophytes were pioneers in establishing themselves on land. This was a very important early event in the progressive evolution of plants under land conditions. Having established themselves on land they followed their own independent course of development (evolution), culminating in an individualistic group without giving rise to higher forms. Among bryophytes the liverworts are more primitive than the mosses, and the latter may have been derived from the former. According to another view the bryophytes have diverged from pteridophytes; later they followed an independent line of evolution ending in a blind alley without giving rise to higher forms. Bryophyta show an advance over algae by the development of archegonia, multicellular antheridia, and a distinct alternation of generations. By the same characters they are a near approach to the pteridophytes but the absence of vascular tissues and the dependence of the sporophyte upon the gametophyte have prevented them from coming to the pteridophytic level. The mode of fertilization by ciliate antherozoids through an aquatic medium has persisted from algae to bryophytes to pteridophytes and to certain lower gymnosperms; this may indicate a connecting link between these groups.

Development of the Sporophyte. The sporophyte is a distinct structure which has evolved from the zygote, and is diploid (with $2n$ chromosomes) and reproduces asexually by spores. It is the product of sexual reproduction and represents the stage between fertilization and subsequent meiosis (reduction division). In most green

algae the zygote represents only a passing diploid (2*n*) phase without *giving rise to a sporophyte. In them the zygote is only a resting body* with protective covering to tide over unfavourable conditions. The [illegible] appearance it passed through successive developmental changes towards greater and greater complexities, and has in due course established itself as the main plant body; from ferns onwards all plants are sporophytes. Certain factors seem to be connected with the gradual development of the sporophyte: immediate germination of the zygote without any rest, prolongation of the vegetative period and delay in meiosis leading to the formation of spores, alternation of generations, land habit, facility of dispersion of spores by wind, sterilization of sporogenous tissue for other functions, and segregation of the spore-producing region from the vegetative region.

The sporophyte, to start with, is a simple structure lying embedded in the gametophytic thallus as a parasitic body, with nearly all its *cells producing spores. This is the case of Riccia. A more complex* type of sporophyte is formed in *Marchantia*. Here the sporophyte grows from the ray of the female receptacle and is already differentiated into a foot, seta and a capsule. In it some of the potentially sporogenous cells give rise to sterile cells—the elaters, and others to spores. Thus a partial sterilization is evident. Besides, the capsule of *Marchantia*, unlike that of *Riccia*, dehisces to liberate the spores for their dispersal. In *Anthoceros* the sporophyte has reached a high degree of complexity in many respects: relatively large size, continued growth in length by a basal meristem, extensive sterilization of the capsule leading to the development of the central axis—the columella, development of chlorophyllous cells and also other cellular differentiation in response to division of labour as a definite move towards an independent existence, partial sterilization of the sporogenous tissue leading to elaters and spores alternately, and all this on a simple primitive type of gametophyte, i.e. thallus. In it the mechanism of liberation of spores by dehiscence of the capsule into two valves is also very efficient. In moss the sporophyte has reached a high degree of specialization, on a highly developed gametophyte. In this plant the extensive amount of sterilization has resulted in an enlarged seta and a very complex capsule. The sporophyte of moss is not still quite an independent plant. *Anthoceros* and moss have, however, followed two independent lines of evolution. At the next higher stage, that is, in fern, the table is turned; *the sporophyte has* [illegible] plant, has elaborately developed roots, stem (often branched) and

leaves (or sporophylls) with a distinct spore-producing region in them. Fern and its relatives like *Equisetum* and *Lycopodium* are homosporous. At the highest level the 'flowering' plants are all sporophytes and are heterosporous, reaching the highest degree of complexity; while the corresponding gametophytes have become reduced to a few cells or nuclei. Thus it is seen that the sporophyte from a simple beginning several millions of years ago has at long last established itself as the highest form of plants—the angiosperms, which now dominate the vegetation of the earth; while the gametophyte, once the predominant feature of the early age, has now become reduced to almost nothing.

1. *RICCIA* (*135 sp.*)

Riccia (FIG. 89) is a thalloid liverwort showing distinct dichotomous branching and taking on a rosette form. It belongs to the family *Ricciaceae*. The thallus is a flattened structure showing a dorsal (upper) surface with a longitudinal groove along the whole length of the mid-rib, and a ventral (lower) surface with usually a row of scales at the apex and a number of unicellular hairy structures known as the rhizoids. The rhizoids are of two kinds—smooth and tuberculate. The thallus is thicker in the middle and thinner at the two margins. The growth of the thallus takes [illegible] ted. The plant grows as a green carpet on wet ground, old damp walls, old tree trunks and moist rocks; rarely it is aquatic, e.g. *Riccia fluitans*. A cross-section of the thallus (FIG. 90) shows the following structure: (*a*) a discontinuous upper epidermis, (*b*) an assimilatory tissue consisting of rows of cells with chloroplasts, leaving narrow irregular air-spaces between the rows for facility of diffusion of gases between the atmosphere and the thallus, (*c*) a lower colourless tissue consisting of fairly big thin-walled cells for storage of water and food, and (*d*) a lower epidermis with many rhizoids.

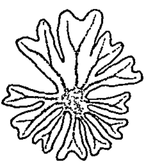


FIG. 89. A *Riccia* plant.

Reproduction. *Riccia* plant is a gametophyte, i.e. it reproduces sexually by gametes. The two kinds of gametes—male and female—are borne in special structures known as the antheridia and the archegonia respectively. Some species are *monoecious* and others *dioecious*. In the monoecious species antheridia and archegonia develop together in the median groove on the dorsal (upper) side of the

thallus. They grow in acropetal succession from the base of the thallus to its apex. Each antheridium (FIG. 91*A*) which is more or less pear-shaped develops in a deep chamber formed by the over-growth of the surrounding tissue of the thallus, and consists of a short stalk, a sterile wall and a compact mass of antherozoid mother cells. Each mother cell by a single division forms two cells, each of which is metamorphosed into a small twisted biciliate male gamete or antherozoid (FIG. 91*B*). Each archegonium (FIG. 91 *C-D*) also lies sunken in a similar chamber. It is a short-stalked, flask-shaped body with a swollen basal portion known as the venter and a narrow tubular upper portion known as the neck which occasionally projects beyond the epidermis and turns purplish. The neck contains a few neck canal cells (usually four) surrounded by six vertical rows of jacket cells, and the venter is occupied by a large cell—the egg-cell and a little higher up a small cell—the ventral canal cell. The egg-cell contains a distinct large nucleus which is the egg-nucleus (female gamete). As the archegonium matures, the neck canal cells and the ventral

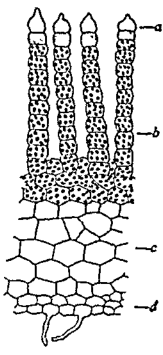
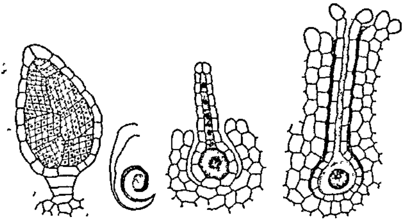


FIG. 90. *Riccia* thallus (see text, p. 484).

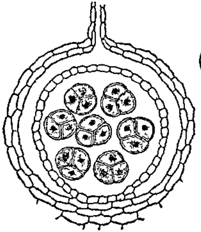


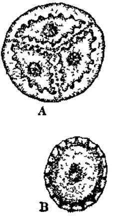
Riccia. FIG. 91. *A*, an antheridium; *B*, an antherozoid; *C*, a young archegonium; *D*, a mature archegonium.

canal cell degenerate into mucilage. Fertilization takes place in the usual way. The antherozoids swim to the archegonium. The

mucilage swells and forces out the cover cells of the neck canal (FIG. 91*D*). As the mucilage dissolves an open passage is established through the neck. The antherozoids enter the archegonium and one of them fuses with the egg-nucleus. After fertilization the ovum clothes itself with a wall and becomes the **oospore**.

Development of Sporophyte. The fertilized egg, i.e. the oospore, gives rise to the **sporophyte**. The sporophyte is a simple spherical body called the **capsule** (FIG. 92). It consists of a spore-sac and a wall surrounding it, the latter made of a single layer. The capsule develops *in situ* within the venter of the archegonium. With the growth of the capsule the venter also grows and invests it. This investing structure is called the **calyptra**. The spore-sac contains a central mass of spore mother cells. Each mother cell undergoes reduction division and forms a *tetrad of spores* (FIG. 93*A*). Eventually by the rupture of the





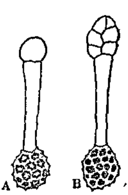


FIG. 92. FIG. 93. FIG. 94.

Riccia. FIG. 92. Sporophyte (capsule) within enlarged archegonium.
FIG. 93. Spores—*A*, spores in a tetrad; *B*, a single spore.
FIG. 94. *A-B*, early stages in the germination of spore.

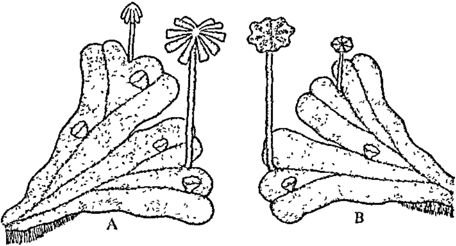
calyptra and the wall of the capsule the spores are set free. Each spore (FIG. 93*B*) is provided with a coat of two layers (three layers according to some authors). The outer layer is cutinized and the inner one made of pectose and callose. The whole coat is irregularly thickened and folded. In the germination of the spore the outer layer bursts and the inner one grows into a *germ tube* which gradually develops into *Riccia* thallus (FIG. 94 *A-B*). The sporophyte develops within the gametophyte and is wholly dependent upon it for its nutrition. In *Riccia* there is no special mechanism for spore dispersal.

Alternation of Generations. The plant passes through two successive generations—gametophytic with *n* chromosomes and sporophytic

with $2n$ chromosomes—to complete its life-history. The gametophytic generation begins with the spore and ends in the gametes—antherozoid and ovum—prior to fertilization; while the sporophytic generation begins with the oospore and ends in the spore mother cells. The gametophyte gives rise to the sporophyte through sexual reproduction, and the sporophyte to the gametophyte through asexual reproduction. Thus there is a regular alternation of generations in *Riccia*.

2. *MARCHANTIA* (*65 sp.*)

Marchantia (FIG. 95 A-B) is a rosette type of thalloid liverwort showing conspicuous dichotomous branching, dorsiventral symmetry and a distinct mid-rib. It belongs to the family *Marchantiaceae*, of which *M. palmata* is a common and widespread species. *Marchantia* grows on damp ground or old walls and spreads rapidly during the rainy season forming a sort of green carpet. It occurs abundantly in the cold climate of the hills. The thallus bears on its undersurface (ventral) a number of unicellular rhizoids of two kinds—tuberculate and smooth-walled, a row of scales along the mid-rib, and 2 or 3 rows



Marchantia. FIG. 95. *A*, female plant with archegoniphores and gemma-cups; *B*, male plant with antheridiophores and gemma-cups.

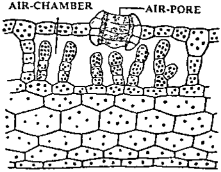
of them on each side of the mid-rib (the outer row being near the margin of the thallus). On the upper surface (dorsal) it bears a number of cup-like outgrowths, known as the gemma-cups, on the mid-rib. The thalli of some plants bear special *male* reproductive branches known as the antheridiophores (FIG. 95*B*) and those of other plants bear special *female* reproductive branches known as the archegoniophores (FIG. 95*A*). The two can be easily recognized—the former having a flat circular brownish lobed disc on the top, and the latter having a green smooth disc projected into distinct rays, at first

ing downwards and later becoming horizontal. The growing poin of the thallus lies in the notch of dichotomy and is represented by one or a few cells.

A section through the thallus (FIG. 96) shows: (1) a single-layered upper epidermi

appear as polygonal areas on the thallus; each air-pore is surrounded by a fev tiers of cells; from the floor of the air-chamber arise short chains of cells, branch-

oil-containing cells here and there; and (4) a single-layered lower epidermis without chloroplasts but with numerous rhizoids and some scales.



Marchantia. FIG. 96. Section through the thallus.

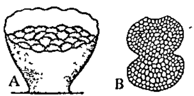


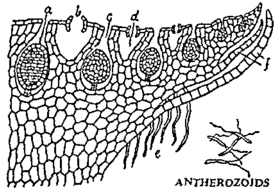
FIG. 97. *A*, gemma-cups; *B*, gemma.

Reproduction. Vegetative reproduction may take place (*a*) by the decay of the old basal portion of the thallus, thus separating the branches, (*b*) by the formation of adventitious branches which get detached from the thallus, or (*c*) by **gemmae** (FIG. 97B) which develop in the **gemma-cup** or **cupule** (FIG. 97A). Each gemma is a small, more or less circular, flattened structure with a conspicuous depression on each side. The growing point lies in the depression. When the gemma gets detached from the gemma-cup it grows out into a dichotomously branched thallus. It is green in colour.

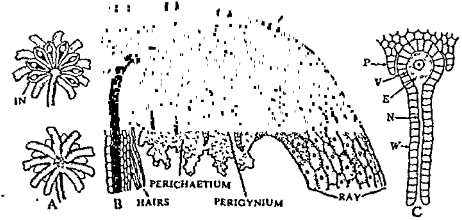
Sexual Reproduction. The thallus is the **gametophyte**, i.e. it reproduces sexually by gametes. *Marchantia* is **dioecious**, i.e. male and female plants are distinct and separate. The male plants bear antheridia or male reproductive organs on special erect branches called antheridiophores (FIG. 95B), and the female plants bear archegonia or female reproductive organs on almost similar branches called archegoniophores (FIG. 95A). The **antheridiophore** (FIG. 98) consists of an erect cylindrical stalk and a more or less circular, commonly

8-lobed disc or receptacle on the top. The stalk has two longitudinal channels on one side from which rhizoids and scales develop. The receptacle bears on its lower side a number of rhizoids and scales,

Marchantia. FIG. 98. Section through the antheridiophore. *a*, antheridium; *b*, air-pore; *c*, ostiole; *d*, air-chamber; *e*, hairs; *f*, scales. Some antherozoids on the right.



and on the upper several small air-chambers and rows of antheridia. Each air-chamber communicates with the exterior through a minute air-pore and has within it chains of green cells, as in the thallus. The antheridia are produced in acropetal order (the oldest towards the centre and the youngest towards the margin) from the segments of 8 growing points which are located at the tips of lobes. Each antheridium (FIG. 98) develops in a cavity lying embedded in the receptacle, and is more or less ovoid in shape; it communicates with the exterior by a narrow canal known as the ostiole. The antheridium is composed of a mass of small cubical cells (antherozoid mother cells) surrounded by a single-layered wall. Each antherozoid mother cell develops a minute biciliate spindle-shaped male gamete known as the antherozoid or spermatozoid. The archegoniophore (FIG. 99) similarly consists



Marchantia. FIG. 99. *A*, (*top*) undersurface of the archegoniophore; *In*, involucre; (*bottom*) upper surface of the same; *B* section through the archegoniophore showing air-chambers with chains of green cells and air-pores, ray, archegonia, etc.; *C*, an archegonium; *P*, perigynium or pseudo-perianth; *V*, venter; *E*, egg-cell; *N*, neck; and *W*, wall.

of a stalk (often longer than that of the antheridiophore) and an 8-lobed star-shaped disc or receptacle with mostly 9 radiating rays or arms, somewhat like the ribs of an umbrella. The rays alternate with the lobes of the disc. The growing point is located at the tip of the lobe of the disc between two rays. Evidently there are 8 such growing points. A group of archegonia develop from the segments of each

points are, however, pushed downwards and inwards with the result that the groups of archegonia come to lie underneath the disc. Each growing point and the youngest archegonium are brought close to the stalk, while the oldest archegonium lies near the margin. The stalk of the receptacle has two longitudinal channels on *one side* with rhizoids and scales, as in the male stalk. On the upper side the receptacle is provided with a number of air-chambers, as in the male receptacle, while groups of archegonia develop on the lower side hanging downwards. A membranous curtain-like outgrowth, known as the **involucre** (or perichaetium), fringed at the edges, is formed surrounding a group of archegonia as a protective covering (FIG. 99*A-B*). Moreover, at the base of each archegonium, ultimately surrounding it after fertilization, there is a cup-shaped outgrowth of it, known as the **pseudo-perianth or perigynium** (FIG. *99B-C*). *The* **archegonium** (FIG. 99 *C*) is a flask-shaped body consisting of a swollen basal portion—the **venter**, a narrow elongated portion—the **neck**, and a very short stout multicellular stalk. The neck of the archegonium, when young, is covered by a lid made of a few 'cap' or 'cover' cells. The venter contains a large cell—the egg-cell or ovum with a distinct large nucleus in it—the **egg-nucleus** (female gamete), and a small ventral canal cell, while the neck contains a row of usually 4-8

lashing with their cilia. As the archegonium matures the neck canal cells and the ventral canal cell degenerate into mucilage; the mucilage swells up in contact with moisture, and the lid is forced open. A clear passage is thus formed. The mucilage contains some protein matter which attracts the antherozoids. They swim to the archegonium through the medium of dews or rain-water and many enter *into the venter through the neck. Finally one of them fuses with the* egg-nucleus in the venter. After fertilization the ovum develops a wall round itself and becomes the **oospore**.

Development and Structure of Sporogonium (FIGS. 100-1). The oospore germinates *in situ* and gives rise to the sporogonium. The sporogo-

nium is the sporophyte, i.e. it reproduces asexually by spores. The oospore divides into an upper cell and a lower. The lower cell further

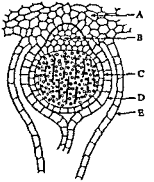


FIG. 100.

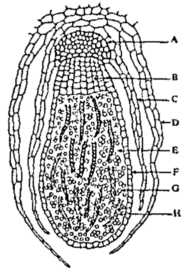
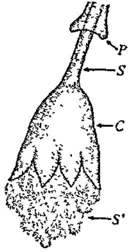


FIG. 101.

FIG. 102.

Marchantia. FIG. 100. A young sporogonium; *A*, tissue of the gametophyte; *B*, foot; *C*, capsule (wall); *D*, archegonium (wall); and *E*, perigynium or pseudo-perianth. FIG. 101. A mature sporogonium; *A*, foot; *B*, seta; *C*, remnant of venter (calyptra); *D*, perigynium or pseudo-perianth; *E*, capsule; *F*, wall of the capsule; *G*, spore; and *H*, elater. FIG. 102. An elater (enlarged).

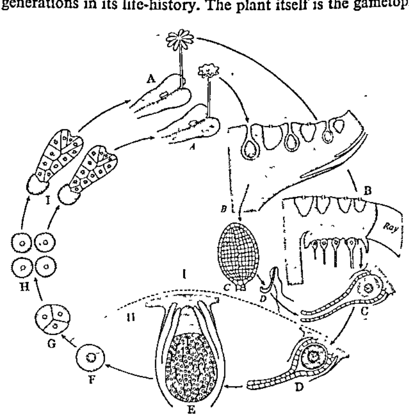
divides and produces a foot and a short stalk called seta which elongates later. The foot penetrates into the tissue of the receptacle and absorbs nutritive materials from it. The upper cell divides and forms the capsule. The capsule consists of a single layer of wall-cells and a mass of small cells (archesporium) inside it. Some of the archesporial cells grow up into elongated, spindle-shaped structures with internal spiral thickenings; these are known as the elaters (FIGS. 101-2). Other cells of the archesporium form spore mother cells. Each spore mother cell divides by the process of meiosis to form *four* spores in a tetrad. After fertilization other parts of the archegoniophore also grow. Thus the wall of the venter grows forming the calyptra which surrounds the capsule (FIG. 101*C*); the neck withers and disappears. The perigynium (FIGS. 100*E* & 101*D*) grows rapidly and ultimately surrounds the sporogonium. The sporophyte is thus adequately protected by



Marchantia. FIG. 103. Sporogonium dehiscing and discharging spores; *P*, perigynium; *S*, seta; *C*, capsule; and *S'*, spores.

the calyptra, perigynium and involucre. As the seta elongates, it pushes the capsule through the calyptra; a remnant of the calyptra may be seen around the capsule (FIG. 101*C*). As the capsule matures, the seta further elongates and pushes the former beyond the perigynium and the involucre. Finally the capsule dehisces, rather irregularly, from the apex to about the middle into a number of segments, and the spores are discharged (FIG. 103). Under humid conditions the elaters adopt a twisting movement and push the spores out of the capsule. The spore germinates and gives rise to a short tube which develops into the *Marchantia* thallus.

Alternation of Generations (FIG. 104). *Marchantia* shows two stages or generations in its life-history. The plant itself is the gametophyte



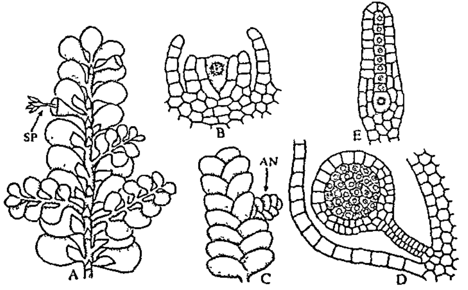
having *haploid* or *n* chromosomes, and the sporogonium the sporophyte having *diploid* or 2*n* chromosomes. The gametophyte reproduces sexually by gametes and gives rise to the sporophyte, and the

sporophyte reproduces asexually by spores and gives rise to the gametophyte. Thus the two generations regularly alternate with each other. All the stages from the oospore to the spore mother cells represent the sporophytic or asexual generation, and all the stages from the spores to the gametes—the ovum and the spermatozoid—represent the gametophytic or sexual generation.

3. *PORELLA* (*180 sp.*)

Occurrence. *Porella* (FIG. 105*A* & *C*) is an acrogynous (see p. 481) leafy liverwort. It grows on moist rocks, tree trunks and old walls, and forms a compact greenish patch, practically covering the medium on which it grows.

Structure. The plant body consists of a slender dorsiventral prostrate stem and leafy branches. The stem bears a large number of rhizoids from its lower side primarily for anchorage. Leaves are arranged in three rows: two rows of dorsal leaves and a row of ventral leaves much reduced in size, called *amphigastria*. Dorsal leaves are unequally bilobed and occur overlapping each other. The plant grows by means of an apical tetrahedral cell which evidently cuts off segments on three sides (FIG. 105*B*).



orophyte; *B*, , male plant the same in mother cells; and *E*, an archegonium.

Vegetative reproduction may take place by the breaking-off of some of the branches, or by the formation of unicellular or multicellular gemmae on the margin or at the apex.

Sexual reproduction. The plant is a gametophyte and evidently reproduces sexually by gametes. *Porella* is dioecious. Male plants (FIG. 105*C*) are usually smaller in size and produce special short and lateral antheridial branches (FIG. 105*D*) which bear antheridia, each in the axil of a leaf (or bract). Paraphyses may be present. Female plants are larger and produce lateral archegonial branches on which archegonia are always borne terminally either singly or in a group. Parap'
surroı
stalk,
giving rise to a minute biciliate antherozoid. Each archegonium (FIG. 103*E*) has a short multicellular stalk, a venter with an egg-cell and an egg-nucleus, a ventral canal cell, a long neck with 6-8 neck canal cells, and a wall. The neck is nearly as broad as the venter. Fertilization takes place in the usual way. The antherozoids, when liberated, swim in water to the archegonium. They enter through the apical opening of the archegonium, and finally one of them fuses with the egg-nucleus. The fertilized egg forms a zygote.

Sporophyte (FIG. 106). The zygote secretes a wall round it and soon increases in size. It divides and re-divides and grows, and soon gives rise to the sporophyte. This consists of a foot, seta and capsule. The **capsule** is globose and is surrounded by a wall (jacket), 2 or 4 layers thick, and encloses short slender spirally thickened elaters and numerous spores. The sporophyte is surrounded by calyptra, perianth and involucre. **Calyptra** is the envelope developed from the venter. The other two envelopes are formed of united leaves (or bracts). When mature, the capsule dehisces by four valves, and the spores are liberated.

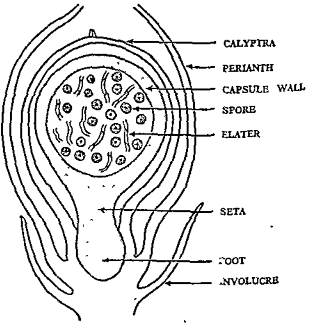


FIG. 106. Sporophyte of *Porella* in longi-section (semi-diagrammatic).

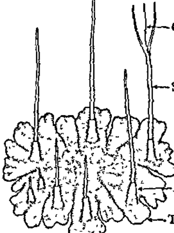
Germination of the spore. Under favourable conditions the spore

germinates and gives rise to a small multicellular body—the protonema. Soon its apical cell becomes active and produces the shoot and leaves of a new *Porella* plant.

4. *ANTHOCEROS* (*60 sp.*)

Anthoceros (FIG. 107), commonly called horned liverwort, is a very interesting plant inasmuch as it shows certain special features in its life-history, particularly helping one to understand the course of evolution in the higher plants. While [illegible] *belonging to a separate class Anthocerotae and order Anthocerotales of Bryophyta.* The features of interest are mostly connected with the sporophyte, and are as follows: (a) semi-independent nature of the sporophyte with the *development of a considerable amount of green tissue and stomata showing thereby a* tendency towards an independent life; (b) a massive foot for greater absorption of water and mineral salts from the gametophyte; further with the decay of the gametophytic tissue the foot may touch the ground and absorb water and mineral salts directly from the soil—another step towards an independent career; (c) complexity of the sporophyte with a considerable development of sterile tissue in it being an early indication of a more complex and quite independent sporophyte at a later stage in the evolution of higher plants; (d) establishment of the sterile axis (columella) representing the beginning of a conducting system; and (e) method of shedding spores comparable to that of ferns and allied plants.

Gametophyte. *Anthoceros* (FIG. 107) is a cosmopolitan plant and grows abundantly both in the hills and the plains in damp soils, hill sides, rotten tree trunks, damp walls, etc. The plant body of *Anthoceros* is a very simple type of gametophytic thallus, usually 2-3 cm. in diameter, with the reproductive organs (male and female or either of the two according as the species is monoecious or dioecious) sunken in it, and at a later stage showing cylindrical deep-green sporophytes standing erect on the thallus. The thallus is a small dark-green plate-like dorsiventral structure, often very irregularly lobed and without mid-rib. While there are many smooth-walled rhizoids developing on the ventral (lower) surface, scales are altogether absent. There are some intercellular mucilage-filled cavities opening to the ventral



Anthoceros. FIG. 107. Thallus of *Anthoceros* with sporophytes; *C*, columella; *S*, sporophyte (capsule); *I*, involucre; and *T*, thallus (gametophytic).

(lower) side of the thallus; these are occupied by colonies of *Nostoc*. The internal structure of the thallus is very simple consisting of a mass of thin-walled parenchyma without any differentiation of tissues. Each cell commonly contains a *single* large chloroplast with a large pyrenoid in it—a character not found in other Bryophyta. The pyrenoid consists of a mass of minute disc- or spindle-shaped bodies which are the rudiments of starch grains.

Reproduction. Vegetative reproduction may take place by the continued growth of the thallus and its separation into segments. In dry regions tubers may be formed on the margin, which may grow into new thalli under favourable conditions. **Sexual reproduction.** *Anthoceros* thallus is the gametophyte and it reproduces sexually by gametes. Species of *Anthoceros* may be monoecious (homothallic) bearing both antheridia and archegonia or dioecious (heterothallic) bearing either of the two. The sexual organs lie embedded *in the* dorsal (upper) surface of the thallus, antheridia appearing first in the monoecious species. **Antheridia** (FIG. 108) grow in small groups

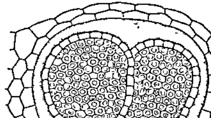


FIG 108

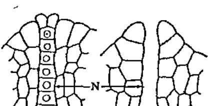


FIG. 109

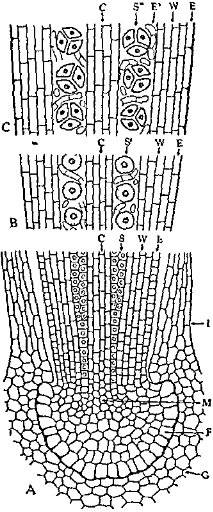
Anthoceros. FIG. 108. Two antheridia in an antheridial chamber (each with a stalk, wall and numerous antherozoid mother cells) FIG 109.

(usually 2-4) within closed chambers, called antheridial chambers, which are filled with mucilage. Each chamber is covered over by a sort of roof made of 1 or 2 layers of cells. Each antheridium consists of a short multicellular stalk, a sterile outer layer (one or more cells thick) and a compact mass of antherozoid mother cells. Each mother cell gives rise to a single minute biciliate antherozoid. **Archegonia** (FIG.

ded in the t

of a venter

neck canal cells, and the venter of a ventral canal cell and an egg-cell with a distinct egg-nucleus in it. At maturity the neck canal cells and the ventral canal cell get disorganized and become converted into mucilage. While the major part of the archegonium remains sunken in the thallus the upper end of the neck only protrudes out of it. When young the neck of the archegonium is covered by four 'cover' cells which separate out later. **Fertilization** is effected in the following way. By the breakdown of the roof of the antheridial chamber an outlet is formed for the antherozoids to escape. They swim to the archegonium and enter through its neck. Finally one antherozoid fuses with the egg-nucleus in the venter. After fertilization a zygote (oospore) is formed, which being diploid (with $2n$ chromosomes) represents the beginning of the sporophytic generation.

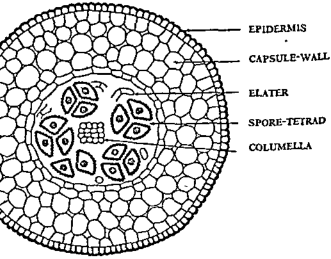


Anthoceros. FIG. 110. Longi[illegible] [illegible] tissue, F, foot; and G, gametophytic tissue.

Sporophyte. The sporophyte develops from the zygote and consists of a **foot** and a **capsule**. It is surrounded at the base by a sheath or involucre formed by an upward growth of the archegonium for a time. Soon after fertilization the zygote grows and completely fills up the venter. It clothes itself with a wall and divides at first vertically into two cells; the second division which is transverse cuts them off into four cells; and the third division at right angles to the first one cuts them off into two tiers of four cells each. The lower tier by further divisions finally gives rise to a massive sterile structure at the base, thus increasing the absorbing surface; this is the foot which looks more or less like an inverted cap (FIG. 110A). The upper tier finally gives rise to the capsule. The capsule (FIG. 107) is a slender

cylindrical deep-green structure, usually 1-3 cm. long, sometimes longer in some species. A longitudinal section through it shows the following regions (FIG. 110). (*a*) A meristematic tissue at the base of the capsule, by the activity of which the sporophyte continues to elongate and the sporocytes, i.e. the spore mother cells, also continue to be formed. (*b*) Centrally a sterile tissue—the columella, consisting

(*d*) Surrounding this there is the capsule-wall which is a jacket of green sterile tissue, 4-8 layers of cells thick, with 2 or sometimes more



Anthoceros. FIG. 111. Transection of a sporophyte through the mature (upper) portion.

chloroplasts in each cell; the outermost layer of this is the epidermis which is strongly thickened and cutinized, and provided with stomata. Because of the presence of the chloroplasts the sporophyte can manufacture most of its food and is only dependent on the gametophyte for water and mineral salts. The sporophyte is, therefore, a semi-independent body. The sporogenous tissue may extend down to the base of the capsule or only half-way down, and may be 1, 2, 3 or

groups of spores in an alternating manner. The elaters are mostly smooth-walled and rarely with spiral bands. Each spore mother cell undergoes reduction division and four spores are formed in a tetrad (FIG. 111). The sporophyte reproduces asexually by these spores.

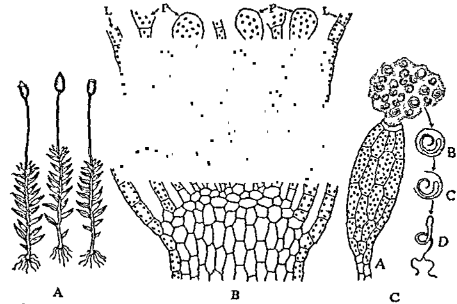
With the formation of the spores the gametophytic generation begins. [illegible] gives rise to an *Anthoceros* thallus.

Alternation of Generations. The life-history of *Anthoceros* is complete in two generations—gametophytic and sporophytic, which regularly alternate with each other. The *Anthoceros* thallus is the main gametophytic body with *haploid* or *n* chromosomes, and the capsule with the foot represents the sporophyte with *diploid* or 2*n* chromosomes. The gametophyte reproduces sexually by gametes and gives rise to the sporophyte, and the latter reproduces asexually by spores and gives rise to the gametophyte. Thus the two generations regularly alternate with each other.

5. A MOSS

Moss (FIG. 112A) occurs most commonly on old damp walls, trunks of trees, and on damp ground during the rainy season, while in winter it is seen to dry up. It is gregarious in habit; wherever it grows it forms a green patch or a soft velvet-like, green carpet. There are about 14,200 species of mosses and allies, some of the common genera are *Funaria*, *Polytrichum*, *Barbula*, *Dicranella*, etc.

The moss plant is small, about 2 cm. or so in height, and consists



[illegible]

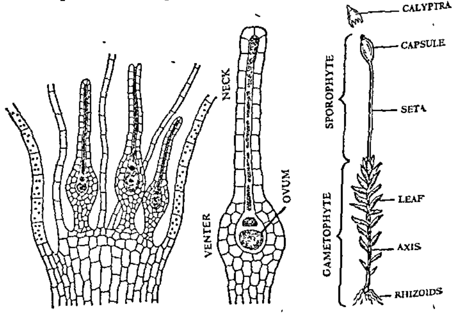
of a short axis with spirally arranged minute green leaves which are crowded towards the apex; true roots are absent; it bears a number of slender multicellular branching **rhizoids** which perform the functions of roots. The axis may be branched or unbranched.

Life-cycle. The life-cycle of moss is complete in two stages—gametophytic and sporophytic. The moss plant itself is the gametophyte and this is followed by another structure, called sporogonium, which grows dependent on the moss plant and is the sporophyte (FIG. 113C).

[illegible]

shoot. The male organ is known as the **antheridium** and the female organ as the **archegonium.** These organs are sometimes intermixed with some multicellular hair-like structures known as the **paraphyses** (*para*, beside; *physis*, growth = offshoot). Antheridia and archegonia may occur together on the same branch or shoot or on two branches of the same plant (monoecious) or on two separate plants (dioecious).

The **antheridium** (FIG. 112 B-C) is a multicellular, short-stalked, club-shaped body. It is packed with a mass of small cells known as



A B C

Moss. FIG. 113. *A*, apex of a female shoot showing three archegonia, three paraphyses and two leaves; *B*, an archegonium; *C*, a moss plant showing the sporophyte growing on the gametophyte.

the antherozoid mother cells and is surrounded by a single layer of cells known as the wall or jacket. The mother cells are regularly

arranged in 5-15 segments (FIG. 112B), while the wall has a terminal lid or operculum consisting of one to many cells. As the antheridium matures the lid is forced open by the internal pressure of the contents, and the mother cells are liberated through the apical opening in a mass of mucilage. The mucilaginous walls of mother cells get dissolved in water and the antherozoids or spermatozoids (FIG. 112C) or male gametes are set free. They are very minute in size, spirally coiled and biciliate; after liberation they swim in water that collects at the apex of the moss plant after rains.

The archegonium (FIG. 113 *A-B*) is also a multicellular body, but is flask-shaped in appearance. It is provided with a short multicellular stalk and consists of two portions: the lower swollen portion is known as the venter (belly) and the upper tube-like portion as the neck, surrounded by a wall or jacket which is single-layered higher up and double-layered in the region of the venter. The neck is long narrow and straight. Within the venter there lies a large cell—the egg-cell or ovum with a distinct nucleus in it—the egg-nucleus (female gamete); above this lies a small ventral canal cell, and higher up in the neck there are many neck canal cells. Except for the ovum other cells mentioned above are functionless and soon degenerate into mucilage. The neck at first remains closed at the apex by a sort of lid, but as the archegonium matures the lid opens as a result of internal pressure by mucilage and allows the antherozoids to enter and pass through it.

Fertilization is effected through the medium of water—rain-water or dew that collects on the moss plants. When the archegonium matures it secretes mucilage with cane-sugar. This attracts a swarm of antherozoids which enter through the neck canal and pass down into the venter; one of them fuses with the egg-nucleus and the rest die out. After fertilization the zygote clothes itself with a wall and is then known as the oospore. The latter germinates *in situ* and gives rise to the sporogonium on the m [illegible] the archegonia of a shoot or [illegible] one zygote (oospore) develops [illegible]

Sporophyte. The sporogonium is the sporophyte, i.e. it bears spores and reproduces by the asexual method. The sporogonium consists of foot, seta and capsule. The seta is the slender stalk which bears the capsule. The foot is the small conical structure which buries it-

[illegible]

manufactures its own food. The oospore divides into two cells—the upper and the lower; the lower cell by repeated divisions forms the seta with the foot, and the upper cell forms the multicellular complex body of the capsule. As the oospore grows the archegonium

gets ruptured somewhere in the middle. The upper half of the ruptured archegonium then forms a sort of cap covering the apex of the

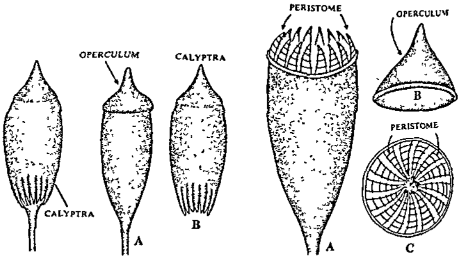


FIG. 114 FIG. 115 FIG. 116

Moss Capsule FIG 114. A capsule covered by calyptra. FIG. 115 *A*, a capsule without calyptra; *B*, detached calyptra. FIG 116. *A*, a capsule showing peristome—open; *B*, operculum; *C*, peristome—closed (surface view)

capsule, and is known as the **calyptra**. The calyptra occurs as a loose cap, and is afterwards blown away (FIGS. 114-5).

The **capsule** (FIG. 117) is a complex body, and more or less pear-shaped in appearance. A longitudinal section through it shows the following regions.

(1) **Operculum.** This is the lid of the capsule, and lies on the top of it. It is a few layers in *thickness. When the capsule* dehisces the operculum comes away as a circular, cup-shaped lid.

(2) **Annulus.** This is a special ring-like layer of epidermal cells, lying around the capsule at the base of the operculum. It is by the rupture of the annulus that the capsule dehisces.

(3) **Peristome.** When the operculum falls off, the top of the capsule is seen to bc [illegible] projections, [illegible] and when the [illegible] (FIG. 116)

(4) **Columella.** This is the solid central column of the capsule. It is sterile, i.e. it contains no spores. Water and food material accumulate here for the developing spores.

(5) **Spore-sac.** This lies around the columella and contains numerous small cells. It is bounded externally by a few layers of cells, and internally by one layer. Each cell of the spore-sac is a spore mother cell. It soon undergoes reduction division to form four spores. The

capsule dehisces at the annulus with the lid falling off. The capsule being seated on a long stalk is disturbed by wind, and the spores are thrown out of the spore-sac.

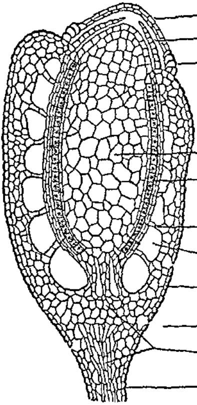


FIG. 117. Capsule of moss in longitudinal section.

(6) **Air-cavity.** This lies as a cylindrical cavity surrounding the spore-sac, and is traversed by delicate strands of cells, known as the trabeculae (sing. trabecula).

(7) **Capsule Wall.** This is composed of (*a*) a few layers of chloroplast-bearing cells just outside the air-cavity, (*b*) a few layers of bigger cells containing water—the sub-epidermis, and (*c*) externally a distinct layer—the epidermis.

(8) **Apophysis.** This is the solid basal portion of the capsule with (*a*) a distinct epidermis bearing a few stomata, (*b*) a sub-epidermis containing chloroplasts, and (*c*) a central region of elongated cells containing water—the water conducting tissue.

FIG. 118. Protonema of moss (note the buds and rhizoids).

Germination of the Spore. After dehiscence of the capsule the spores are scattered by the wind and germinate under favourable conditions.

The spore grows out into a short tube which lengthens and ultimately forms a green, much-branched filament; this is known as the **protonema** (FIG. 118). It produces here and there long slender and brown rhizoids, and a number of small lateral buds. These lateral buds develop into new moss plants which form a colony again. Thus the life-cycle of moss is completed.

Alternation of Generations (FIG. 119). Moss plant shows two generations which regularly alternate with each other, and the life-history

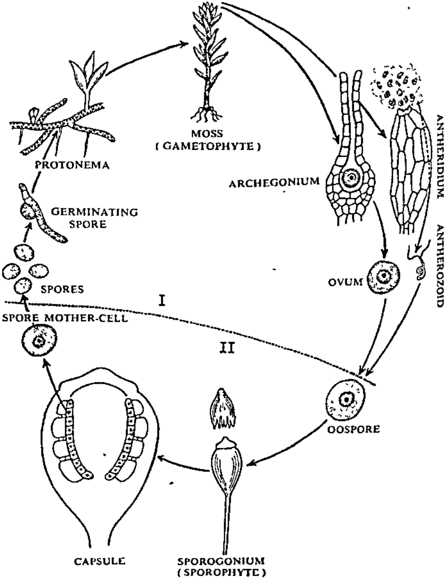


FIG. 119. Life-cycle of moss. *I*, gametophytic generation (haploid or n) and *II*, sporophytic generation (diploid or $2n$).

is only complete when the plant passes through these two generations. The moss plant itself is the gametophyte (or gamete-bearing plant), and the sporogonium is the sporophyte (or spore-bearing plant). Through sexual reproduction by gametes (antherozoid and ovum) the gametophyte gives rise to the sporophyte, and through *asexual reproduction by spores the sporophyte gives rise to the* gametophyte. In the life-history of moss the reduction of chromosomes to haploid or n takes place for the first time in the formation of spores from the spore mother cell. The spore is, therefore, the beginning of the sexual or gametophytic generation, and the various stages from the spore to the antherozoid and ovum represent the gametophytic or sexual generation because in all of them the chromosome number is n. The antherozoid and the ovum fuse, and the chromosome number is doubled, i.e. $2n$ is restored in the oospore. The oospore, therefore, represents the beginning of the asexual or sporophytic generation, and the oospore, sporogonium and spore *mother cells represent the sporophytic or asexual generation because* in all of them the chromosome number is $2n$.

Vegetative Reproduction. The gametophytic plant reproduces vegetatively in a variety of ways: (1) by the formation of multicellular 'gemmae' which develop in groups usually at the apex of the leaf or at the apex of a comparatively long branch; they get detached and germinate in a moist soil, putting out a proto-

separation of protonemal branches.

Some of the cells of the sporogonium may also develop protonema which by budding gives rise to moss plants. This is a case of apospory.

Comparison between Liverworts and Mosses. (1) In liverworts the gametophyte is mostly thalloid (except leafy Jungermanniales) and dorsiventral; whereas in mosses it is leafy and radial. In both the gametophytes are the main plants and are green in colour performing photosynthesis, and they take to sexual reproduction through highly developed gametes and gametangia. Both show regular alternation of generations.

(2) Leaves in the leafy liverworts (e g. *Porella* of Jungermanniales) have no

ranched;

(4) In liverworts the protonema is mostly absent or small; while in mosses it is distinct and well developed.

(5) The sporophyte in *Riccia* is simple and lies embedded in the thallus. In *Marchantia* it is differentiated into foot, seta and capsule; it comes out of the thallus and shows the beginning of sterilization of sporogenous tissue in the form of elaters. In both the sporophyte is non-green and is wholly parasitic upon the gametophyte. The sporophyte of *Anthoceros* is a green elongated complex body with foot, seta and capsule, and it shows further sterilization of sporogenous tissue (elaters and a small columella); it is only partially parasitic upon the game-

tophyte. In mosses the sporophyte has reached a high degree of development and complexity with distinct foot, seta and capsule; it shows further differentiation of sterile tissue (columella) and sporogenous tissue; and being green it is only partially parasitic upon the gametophyte.

(6) Elaters are mostly present in liverworts; while in mosses they are absent.

Chapter 7 PTERIDOPHYTA

Classification of Pteridophyta (10,000 sp.)

Class I Lycopodinae (940 sp.). **Order 1.** Lycopodiales (180 sp.), e.g. *Lycopodium*. **Order 2.** Selaginellales (700 sp.), e.g. *Selaginella*. Order 3.

[illegible]

to the sporogenous tissue.

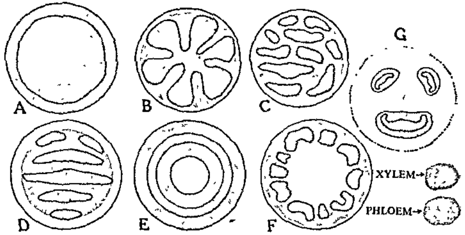
[illegible]

from some bryophytes. Of the three groups mentioned above Lycopodinae seems to be comparatively old although it has given rise to heterosporous condition (e.g. *Selaginella* and *Isoetes*). Equisetinae is more advanced than the former; while Filicinae is the most advanced group. Among the orders of this group the eusporangiate ferns are regarded as ancient and the leptosporangiate ferns modern.

Types of Steles in Pteridophyta (FIG. 120). The vascular tissues as a whole together with the associated tissues making up the central column of the root, stem and leaf constitute a stele (*stele* means a column). The stele thus consists of all the tissues, mainly, however, the vascular, from the centre to the pericycle and is surrounded by

the [illegible]
of [illegible]
fere[illegible] types [illegible]
evolution. In this respect Pteridophyta are of special interest since they show, often with natural gradations, all the stelar types, as described below. Within each type a certain amount of variation or gradation is noticed. The theory of the stele was formulated by Van Tieghem about the middle of the 19th century. But Jeffrey in 1866 modified it and introduced the terms *protostele* and *siphonostele*, and *said that the latter had originated from the former.*

(1) Protostele (*protos*, first). This is the simplest and the most primitive type of stele. In it the vascular tissues alone form a solid central column *without any pith*. In the simpler and earlier types xylem forms the central core surrounded by a ring of phloem and bounded by a layer of pericycle on the outside (FIG. 120*A*). In the



Types of Steles. FIG. 120. *A*, [illegible] in *Lycopodium serratum*; *C*, ha[illegible] in *L. clavatum*; *E*, amphiphloic [illegible] siphonostele in *Osmunda*; *G*, dictyostele in *Dryopetris*.

more complex types xylem and phloem form separate plates with the protoxylem lying at the extremities. Thus xylem may appear as a star-shaped structure with phloem alternating with its rays; this is the radial type of stele, otherwise called actinostele (FIG. 120*B*), as in *Lycopodium serratum* and *L. phlegmaria*. In the second type xylem appears as small bands with phloem intermixed with them; this is *the mixed type of stele, otherwise called* haplostele (FIG. 120*C*), as in *L. cernuum*. A third type consists of transverse plates of xylem alternating with parallel bands of phloem; this is the parallel-banded stele, otherwise called plectostele (FIG. 120*D*), as in *L. clavatum*. Protostele occurs in many ferns and certain other pteridophytes, e.g. *Lygodium*, *Gleichenia*, *Isoetes*, *Lycopodium*, some species of *Selaginella*, roots of

all ferns, etc. This type of stele is also found in the pithless roots of many angiosperms and stems of some aquatic angiosperms.

With the development of the pith and the presence of leaf-gaps (see p. 509) the pattern of distribution of xylem and phloem changes, [illegible] outside of xylem. Siphonostele is thus a hollow or tubular stele. There are two types.

(*a*) Amphiphloic Siphonostele (*amphi*, on both sides). Here xylem [illegible]

[illegible] the angiosperms it is found in *Cucurbitaceae*.

(*b*) Ectophloic Siphonostele (*ectos*, outside). Here also xylem forms [illegible] *chium*, and also in *Equisetum*. Gymnosperms and dicotyledons show an advanced type of ectophloic siphonostele. Here the leaf-gaps being large and indistinguishable from the interfascicular areas, and the pith and the cortex becoming connected by wide bands of parenchyma, the vascular system is broken up into separate vascular bundles.

Origin of Siphonostele. It is an admitted fact that siphonostele has been derived from protostele. But regarding the origin of pith there are two diametrically [illegible]

rays (expansion theory). This is the generally accepted view. According to Jeffrey, however, the pith is extrastelar in origin; first, by obliteration of the inner endodermis, and second, by the intrusion of the cortical tissue inwards, finally giving rise to the pith in the centre (invasion theory). This is not, however, a very convincing view.

(3) **Dictyostele** (*dictyo*, net). This is a much dissected type of stele derived from the siphonostele, and is the most advanced type. The presence of numerous leaf-gaps caused by leaf-traces breaks up the stele into a network of separate strands, each constituting a concentric bundle (FIG. 120*G*). This is found characteristically in many

species of *Polypodiaceae*, e.g. *Pteris, Pteridium, Polypodium, Aspidium, Dryopteris*, etc., and some species of *Selaginella*.

Leaf-traces and Leaf-gaps. It must be noted that the vascular cylinder is continuous through the whole plant body. At the node a strand of vascular tissue leaves the cylinder, passes out through the cortex and goes into the leaf; this strand of vascular tissue is called the leaf-trace The leaf-trace while leaving the vascular cylinder of the stem causes small breaks or openings in it: each break in the vascular cylinder of the stem is called the leaf-gap The leaf-gap occurs in the vascular cylinder just above leaf-trace and is filled up with parenchyma. Above the leaf-gap the vascular cylinder again becomes continuous so that a transection at the node of the stem shows the break in the vascular cylinder, while a section at the internode above the leaf-gap shows a continuous ring-like cylinder. The presence of numerous leaf-gaps breaks up the vascular cylinder into a sort of network.

A reduction of the vascular tissues is noticed from gymnosperms and woody dicotyledons where the activity of the cambium is at its maximum, to herbaceous dicotyledons with much less or no activity of the cambium and sometimes absence of interfascicular cambium, finally to monocotyledons without cambium (except in a few cases) This reduction series indicates the trend of evolution from woody types (primitive condition) to herbaceous types (advanced condition).

1. *LYCOPODIUM* (*185 sp.*)

Lycopodium, commonly called club-moss, is a much branched herbaceous plant found abundantly in the hills at a comparatively high altitude. The plant body consists of creeping rhizomes which give

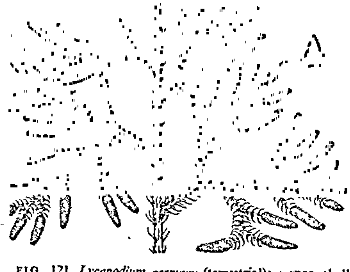


FIG. 121. *Lycopodium cernuum* (terrestrial); a sporophyll with a sporangium shown separately.

off slender elongated aerial branches from the upper side and adventitious roots from the lower. The branches are densely covered with

numerous small narrow pointed leaves. *Lycopodium* mostly shows characteristic dichotomous branching, but some species are monopodial. Most species of *Lycopodium* are terrestrial, while in the tropical forests there are some epiphytic species with pendent branches, e.g. *L. phlegmaria* and *L. squarrosum*. Both of them are common in Assam.

FIG. 122.

FIG. 123

FIG. 122. *Lycopodium phlegmaria* (epiphytic). FIG. 123. *L. clavatum* (terrestrial); a sporophyll with a sporangium shown separately.

and the stele. It varies considerably from species to species in its width, structure

be sclerenchymatous. (3) Endodermis—a single layer of small thin-walled cells surrounding the central stele; however, it is not well defined in all cases. (4) Stele—this is the central cylinder of the vascular system—xylem and phloem, surrounded by a few-layered, thin-walled parenchyma comprising the pericycle. The

plectostele. The radial type of protostele is most primitive, while the two other types are more advanced. In *Lycopodium* xylem is always exarch with protoxylem towards the pericycle, and metaxylem towards the centre. Protoxylem consists of

a few narrow annular and spiral tracheids, and metaxylem of large scalariform tracheids. Phloem consists of sieve-tubes and phloem parenchyma.

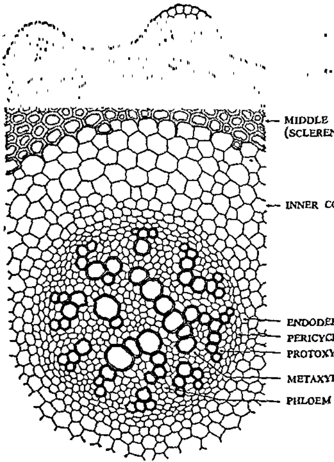


FIG. 124. *Lycopodium* (*L. cernuum*) stem in transection.

Sporophyte. *Lycopodium* plant is the sporophyte, i.e. it reproduces asexually by spores which are borne by specialized leaves called **sporophylls**. The sporophylls resemble the vegetative leaves but are smaller in size. They are aggregated together, being spirally arranged, at the apex of the vegetative branch or of the special reproductive branch in the form of a cone, called sporangiferous spike or strobilus (FIG. 125). All the sporophylls are of the same kind and so also are the sporangia and the spores. *Lycopodium is thus homosporous*. The sporangium has a short multicellular stalk and is borne on the upper surface of the sporophyll close to its base. It consists of a wall commonly made of a few (3 or more) layers of cells, and an inner mass of sporogenous cells or spore mother cells. By reduction division spores are formed in tetrads from these cells.

Gametophyte (FIGS. 126 *A-B*). After dehiscence of the sporangium

the spores are scattered by the wind. The spores are remarkably long-lived, often *retaining their viability for a number of years*. In many

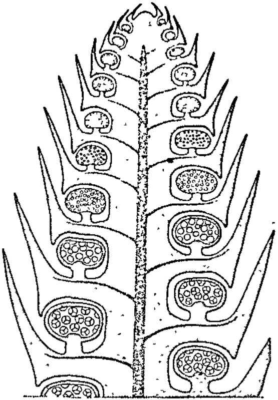
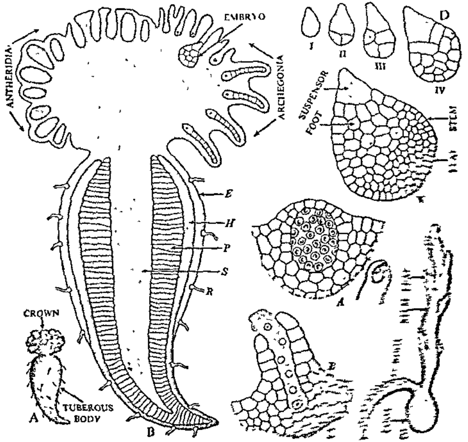


FIG. 125. *Lycopodium* spike in longitudinal section, showing sporophylls, sporangia and spores.

species the spores do not germinate for several months or *sometimes even years* after shedding. Even after the germination begins the rate of growth is slow. In *L. cernuum*, a common Indian species, the spores germinate within a few days and the growth of the gametophyte is completed in the same season. The spore, in any case, on germination gives rise to the gametophyte or prothallus. The gametophyte may be subterranean or sub-aerial, and vertical or partially horizontal. In the sub-aerial type the aerial portion turns green in colour and bears the sexual organs. In size it is about 2 or 3 mm. in length. The subterranean type is much bigger than the first type but non-green in colour. In shape the gametophyte may be a cylindrical or tuberous body with a lobed crown or it may be broad and irregularly cup-shaped. The crown bears the sexual organs. The tuberous portion shows a complicated internal structure, *being differentiated* into distinct regions, and is *always* associated with an endophytic (symbiotic) fungus which infects a definite region of it at an early stage of gametophyte-development. But for this fungal infection the growth of the gametophyte becomes arrested. Some rhizoids are produced from the epidermal layer. (For detailed structure of the gametophyte see FIG. 126*B* and caption.) The game-

tophyte of *Lycopodium* is monoecious bearing both antheridia and archegonia. **Antheridia and Archegonia** (FIGS. 126C). Numerous antheridia and archegonia are formed in the upper lobed portion



[illegible]; B, the [illegible] palisade [illegible] gans—A, a [illegible] antherozoid [illegible] he development [illegible] on the [illegible] Morphology by [illegible] McGraw-Hill Book Company [illegible]

(crown) of the gametophyte. The [illegible] cal consisting of a wall made of one [illegible] of spermatogenous cells (anther[illegible] partially sunken in the tissue of [illegible] (antherozoids) are minute, [illegible] curved, and biciliate. The [illegible] ture and lies almost wholly [illegible] the upper portion of the [illegible] of a narrow venter and a [illegible]

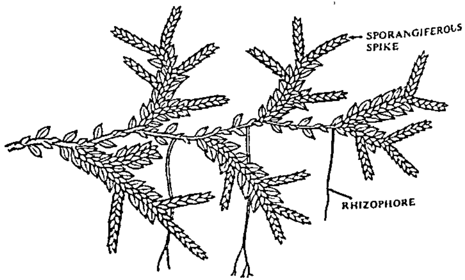
canal cells (1-16, commonly 4-6). The venter contains a single large cell—the egg-cell with a distinct nucleus in it—the egg-nucleus (female gamete), and a ventral canal cell. All the canal cells soon get disorganized.

Embryo (FIG. 126D). After fertilization which takes place in the usual way the fertilized egg or oospore divides into two cells—outer and inner. The outer cell is the suspensor cell which is elongated but not functional, while the inner one is the embryonal cell. The latter by successive divisions gives rise to two tiers of four cells each, of which the outer tier, i.e. the one next to the suspensor, produces the foot, and the inner tier produces the stem on one side and the leaf on the other side. The root develops later from the inner tier close to the leaf, and then the foot becomes disorganized (FIG. 126E).

Alternation of Generations. *Lycopodium* plant is the sporophyte (with $2n$ chro[illegible]
to the pr[illegible]
somes). 1. [illegible]
phyte again. These two generations (sporophyte including all the stages from oospore to spore mother cells, and gametophyte including all the stages from spores to gametes) regularly alternate with each other.

2. *SELAGINELLA* (*700 sp.*)

Selaginella (FIG. 127) grows in damp places in the hills and in the



Selaginella. FIG. 127. A portion of a plant showing four rows of leaves, a number of spikes and three rhizophores.

lains. It is a slender much branched plant creeping on the wall or n the ground. The slender stem bears four rows of leaves—two ows of small leaves on the upper surface and two rows of larger eaves at the two sides. A scaly structure, called ligule (see FIG. 129), levelops on the upper (ventral) surface of each leaf above its base A long slender root-like organ is given off from the undersurface of he stem at the point of branching; this is known as the rhizophore (root-bearer). In some species the rhizophore bears small fibrous oots at the tip. It has no root-cap and grows exogenously like the [illegible] and in [illegible]; it may [illegible]

Internal Structure of the Stem (FIG. 128). (1) **Epidermis**—a single layer with a cuticle. (2) **Sclerenchyma**—a few layers of sclerenchyma occur below the epidermis. (3) **Ground tissue**—a continuous mass of thin-walled, polygonal cells. (4) **Steles**—usually 2 or 3; each stele is surrounded by an air-space which is formed

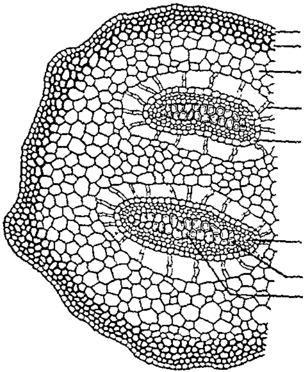


FIG. 128. *Selaginella* stem in transection.

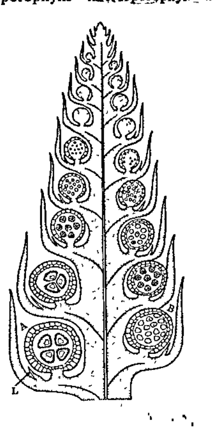
as a result of breaking down of some of the inner layers of the cortex, and remains suspended in the air-space by delicate strands of cells, called trabeculae (sing. trabecula). Casparian strips are often present in the trabecular cells and appear as dots or thin walls. The stele, when young, is surrounded by a single-layered endodermis; later on the cells of the endodermis separate laterally and elongate considerably in the radial direction. These long radiating cells formed

as a result of stretching of the endodermal cells are the trabeculae; in the mature stele they act as bridges across the air-space. Each stele which is concentric in nature consists of (*a*) pericycle, (*b*) phloem, and (*c*) xylem. Internal to the air-space there is a layer, sometimes two, of rather large but thin-walled cells—the pericycle. Phloem surrounds the central spindle-shaped xylem. Protoxylem lies at the two ends and metaxylem in the middle.

Life-cycle. The life-cycle of *Selaginella* is complete in two stages—sporophytic and gametophytic—the former much more complicated and the latter much simpler than the previous cases. *Selaginella* plant is the sporophyte and this is followed by another *two* structures, called prothalli, which are the gametophytes (male and female).

Sporophyte. *Selaginella* plant is the sporophyte. It bears *two* kinds of spores—microspores and megaspores—and reproduces asexually by them.

Sporophylls, Sporangia and Spores. *Selaginella* bears two kinds of sporophylls—microsporophylls and megasporophylls. Both kinds of sporophylls may occur together in the same cone, or they may be borne in two separate cones either on the same plant (monoecious) or on two separate plants (dioecious). All the sporophylls are nearly of equal size and spirally arranged, usually in four rows, round the apex of the reproductive shoot, in the form of a more or less distinct four angled *cone*, called the sporangiferous spike (FIGS. 127 & 129) or strobilus. The sporophylls are similar to the vegetative leaves in



cells. But only one of them divides, while others become disorganized. It undergoes reduction division

up in the megaspore. The microsporophyll similarly bears in its axil a microsporangium with usually

spores; *L*, ligule.

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of a short stout stalk and a capsule; the wall of the capsule is composed of three layers of cells. The megasporangia are somewhat larger than the microsporangia.

Gametophytes. The two prothalli (male and female) are the gametophytes, i.e. they bear male gametes or antherozoids and female gamete or ovum, and reproduce sexually by them.

Germination of the Megaspore: Female Prothallus (FIGS. 131-2). The megaspore-nucleus divides repeatedly by the process of free cell formation and gives rise to a mass of tissue within it. This is the

FIG. 130

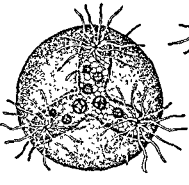

FIG. 131

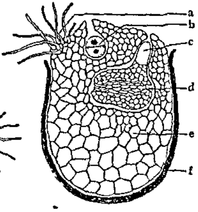

FIG. 132

oil. This cavity subsequently becomes filled with cells. Further development of the gametophyte exerts pressure on the spore-wall which ruptures by a tri-radiate fissure, and the gametophyte becomes partially exposed (FIGS. 131-2). *The gametophyte is partially endosporous. It is a much reduced structure* compared to that of fern and allied plants. It is also *not an independent structure* like that of fern and allied plants, being enclosed by the spore-coat and nourished by the food stored in the spore. A number of archegonia and some groups

oospore is the beginning of the sporophytic generation because $2n$ chromosomes are met with for the first time in the oospore, and all the stages from the oospore to the spore mother cells represent the

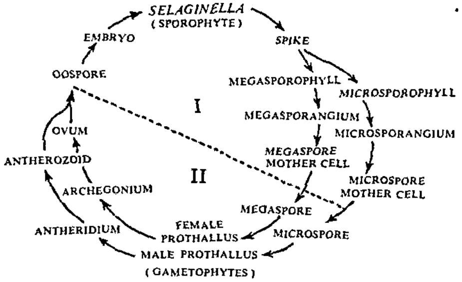

FIG. 137. Life-cycle of *Selaginella* (diagrammatic) showing alternation of generations. *I*, sporophytic generation (diploid or $2n$); and *II*, gametophytic generation (haploid or n).

sporophytic generation. Reduction division takes place in the formation of the spores; so all the stages from the spores (micro- and mega-) to gametes (antherozoid and ovum) with n chromosomes represent the gametophytic generation.

3. *EQUISETUM* (25 sp.)

Equisetum (FIG. 138), commonly called horsetail, is a much-branched herb. It is widely distributed, especially in the cool and temperate regions of the world, and is usually abundant in marshy places or by the side of a spring or stream of water in the hills. *Equisetum*
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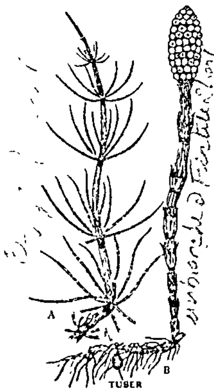
h

usually sterile and vegetative in function, while unbranched shoots are fertile and short-lived; after the production of spores they soon dry up. In some species, however, branched shoots are fertile. Leaves are minute and scaly, and form a whorl at each node. These leaves are free and pointed at their tips but united below to form a sheath

round the base of the internode. The lateral branches develop alternating with these leaves and grow upwards piercing the sheath. In consequence of reduction of leaf-laminae, the branches become green and perform photosynthesis. Roots are slender, adventitious and much branched developing from each node of the rhizome.



Equisetum. FIG. 138. *A*, a vegetative shoot with whorls of branches; *B*, a fertile shoot with a spike.

Internal Structure of the Stem (FIG. 138). The stem has distinct nodes and internodes, with longitudinal ridges and furrows. The internal structure is as follows: (1) Epidermis—a single outer layer of cells with a deposit of silica in their outer walls. It is wavy in outline and has stomata in two rows in the furrow. (2) Sclerenchyma—sclerenchyma develops, specially in the ridges, below the epidermis, interrupted in the furrows by the underlying cortex. (3) Cortex—this is many-layered, and in the middle of it large air-canals, each corresponding to a [illegible]

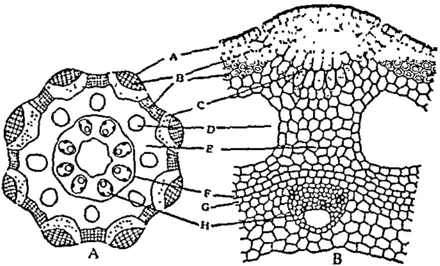
(4) Endodermis—cortex is demarcated from the stele by a definite layer of endodermis. (5) Pericycle—the layer lying internal to the endodermis is the pericycle. (6) Vascular bundles—these are closed, collateral, and arranged in a ring. Each vascular bundle is very feebly developed with xylem on the inner side and a small patch of phloem on the outer; xylem consists of some scalariform tracheids; there is an air-passage in it. (7) Pith cavity—there is a big air-cavity corresponding to the pith.

Life-cycle. The life-cycle of *Equisetum* is complete in two stages—sporophytic and gametophytic. The plant itself is the sporophyte and this is followed by another structure, called prothallus, which is the gametophyte (FIG. 141*A*).

Sporophyte. The *Equisetum* plant (FIG. 138) is the sporophyte, i.e. it reproduces asexually by spores which are borne by specialized leaves called sporophylls.

Sporophylls, Sporangia and Spores. The sporophylls are very much specialized in structure and take the form of somewhat flattened, hexagonal or circular discs, each supported on a short stalk, and are aggregated together in whorls at the apex of a usually unbranched non-green aerial shoot in the form of a cone, called the sporangiferous

spike or strobilus (FIGS. 138*B* & 140*A*). The lowest whorl is sterile and forms a ring at the base of the spike. In *Equisetum*, as in all



higher plants, the reproductive region is quite distinct from the vegetative region. Each sporophyll (FIG. 140*B*) has the form of a stalked

is green in colour containing numerous minute chloroplasts, and

140 *D-E*), attached to the spores at their centre; the elaters appear as four distinct appendages. They are extremely hygroscopic; when the air is dry they unwind and stand out stiffly from the spore, and when the air is moist they roll up s

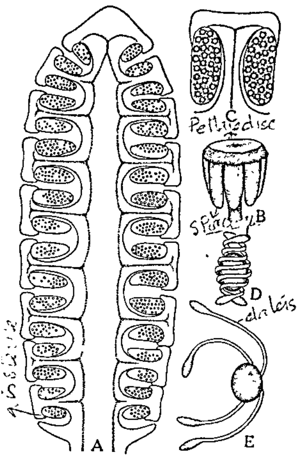
Elaters. The elaters expand and help

gium. The spores become entangled

away in clusters by air-currents; this helps the germination of spores close together for facility of fertilization.

Gametophyte. The prothallus (FIG. 141*A*) is the gametophyte, i.e. it bears gametes—male (antherozoid) and female (ovum), and repro-

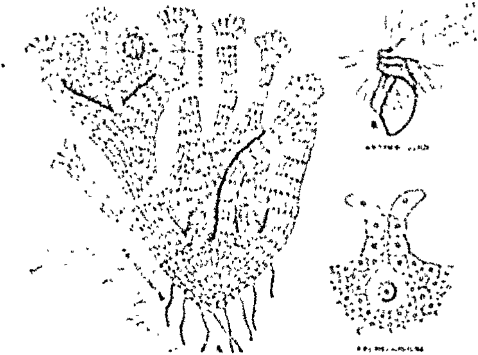
easily grown in culture in the laboratory. On germination they give rise to prothalli which are small in size, dull brownish-green in colour and much branched (lobed). The prothalli in most species are usually 3-6 mm. in diameter; in *E. debile*, however, they may be as big as 3 cm. in diameter. Prothalli, when they grow under favourable conditions, are normally monoecious bearing both antheridia and archegonia. However, if they grow crowded together in the field or in culture they are dioecious, the smaller ones being male and the bigger ones female. It has been seen that the latter bear antheridia with age. This imperfect dioecism may be due to unfavourable conditions of growth. In *E. arvense*, however, about half of the spores give rise to male prothalli and the remaining half to female prothalli. If no fertilization takes place, the latter may produce antheridia. Prothalli usually live long, sometimes exceeding a period of two years. The prothallus is the gametophyte since it bears antheridia or archegonia or normally both. The sexual organs begin to appear in the



the same in longi-section, *D*, a spore with elaters coiled; and *E*, the same with elaters uncoiled.

less spherical in shape and contains numerous antherozoid mother cells (usually 256). In each mother cell one antherozoid or male gamete is produced. It is a large spirally coiled and multiciliate body (FIG. 141*B*). Archegonia always develop in the axial region of the prothallus and in the axil of a branch of it. Each archegonium (FIG. 141*C*)

is flask-shaped with a swollen venter and a narrow neck, and contains an egg-cell or ovum with a distinct egg-nucleus in it, a ventral canal cell and a neck canal cell.



Equisetum. FIG. 141. *A*, prothallus (monoecious); *B*, an antherozoid; *C*, a mature archegonium.

Fertilization. The method of fertilization is the same as that of ferns. After fertilization the oospore gives rise to an embryo which

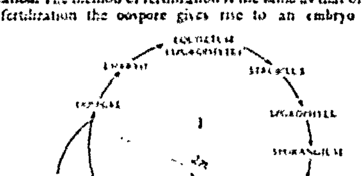


FIG. 142. Life-cycle of *Equisetum* (diagrammatic) showing alternation of generations. *I*, sporophytic generation (diploid or $2n$); and *II*, gametophytic generation (haploid or n).

develops into a branching rhizome. This then produces erect aerial shoots and a number of adventitious roots.

Alternation of Generations (FIG. 142). *Equisetum* plant shows in its life-history a regular alternation of generations. The plant itself is the sporophyte, and the prothallus—monoecious or dioecious—is the gametophyte. As in fern, the sporophyte or *Equisetum* plant reproduces asexually by spores and gives rise to the gametophyte or prothallus, and the prothallus reproduces sexually by gametes—antherozoid and ovum, and gives rise to the sporophyte. Thus the two generations regularly alternate with each other. The sporophytic generation begins with the oospore and ends in the spore mother cells because in all these stages $2n$ chromosomes are met with; while the gametophytic generation begins with the spores and ends in the gametes (antherozoid and ovum) because in all these stages there are only n chromosomes.

4. A FERN Seed less i.e flowerless plant

Ferns (FIG. 143) are a group of highly developed cryptogams and are

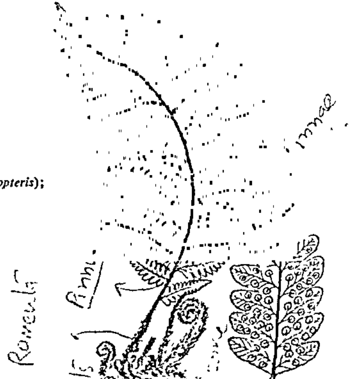


FIG. 143.
A fern plant (*Dryopteris*); *right*, portion of a pinna with sori.

widely distributed all over the world. They grow abundantly in cool shady moist places, both in the hills and in the plains. The stem is

mostly a rhizome, but is sometimes erect and aerial, as in tree ferns. Roots are adventitious (fibrous) growing usually in clusters from the rhizome. Le ... vhen young (FIG. ... The lateral leafle ... nnae (sing. pinna); sometimes these are again more or less deeply pinnately lobed, and then each lobe is known as the pinnule. The stem and the petiole are covered with numerous brownish scales, known as the ramenta. There are about 7,600 species of ferns. Some of the common genera are *Dryopteris*, *Nephrolepis*, *Pteris*, *Polypodium*, *Adiantum*, etc. X. Without Vessel and [illegible]

Internal Structure of the Fern Stem (or Petiole). (1) **Epidermis**—a single layer of cells with the outer walls thickened and cutinized. (2) **Sclerenchyma**—a few layers of sclerenchyma occur below the epidermis. (3) **Ground tissue** is made up of a continuous mass of polygonal parenchymatous cells. (4) **Endodermis**—a single layer of narrow cells surrounding each stele; this layer is often much thickened,

The sex organs are [illegible]

Archego[illegible]

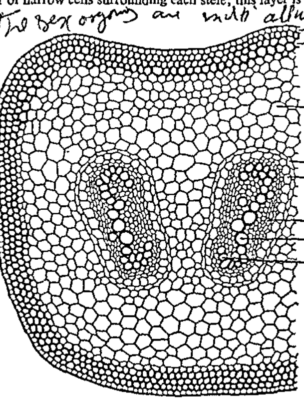


FIG. 144. Fern petiole in transection.

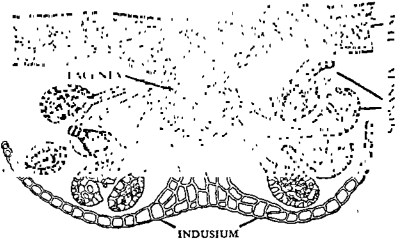
particularly on the inner side. (5) **Steles**—in the young stem or petiole the stele is more or less horseshoe-shaped, but in the older part the stele is broken up usually into two or three smaller steles. Each stele consists of (*a*) pericycle, (*b*) phloem and (*c*) xylem. Pericycle surrounds the stele as a single layer (sometimes a double layer, particularly at the sides) and contains starch grains. ...

surrounds the central xylem, the bundle being concentric, and consists of sieve [illegible]
form tracheids.

Life-cycle. The life-cycle of fern is complete in two stages—sporophytic and gametophytic. The fern plant is the sporophyte and this is followed by another structure, called prothallus, which grows in the soil independent of the fern plant and is the gametophyte (FIG 147).

Sporophyte. The fern plant (FIG 143), as stated above, is the sporophyte, i.e. it bears spores and reproduces by the asexual method.

Sporangia and Spores. On the undersurface of the ordinary vegetative leaf or specially modified foliage leaf, i.e. the **sporophyll** (as the spore-bearing leaf is called), a number of dark brown structures, pale-green when young, may be seen; these are called **sori** (sing sorus). They develop on the veins, and are arranged in two rows in each leaflet or pinna of the leaf. Each sorus (FIG. 145) consists of a large number of sporangia which are covered over by a reniform

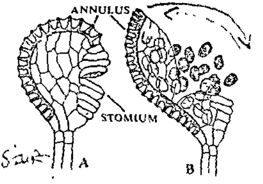


Fern FIG. 145. Section through a sorus.

or kidney-shaped shield, called the indusium. The sporangia and the indusium develop from a papilla-like outgrowth of the leaf; this outgrowth is called the placenta.

Each sporangium (FIG. 146) consists of a long multicellular stalk and a capsule which is biconvex. Inside the capsule lies a mass of very small grains; these are the spores. At first there are 16 spore mother cells in the capsule; these undergo reduction division into 32 daughter cells. The daughter cells then divide mitotically and 64 spores are formed. The wall of the capsule consists of a single layer

of thin-walled cells, with a specially thickened and cutinized band or ring running round the margin of the capsule. This ring which is incomplete and thin-walled on one side is called the **annulus**, and its unthickened portion is known as the **stomium**. When the spores mature they increase in size, and under dry conditions the capsule bursts at the stomium, liberating the spores. When the capsule bursts, the annulus bends back exposing the spores, and then suddenly returns to its original position, ejecting the spores with a jerk by this process.



Fern. FIG. 146. Sporangia (capsule and stalk); *A*, capsule just open at the stomium; *B*, capsule has burst with the annulus bending back.

The fern plant is *homosporous*, i.e. it bears only one kind of spores.

Gametophyte. The prothallus (FIG. 147) is the gametophyte, *i.e. it* bears gametes and reproduces by the sexual method. Under favourable conditions of temperature and moisture the spore germinates.

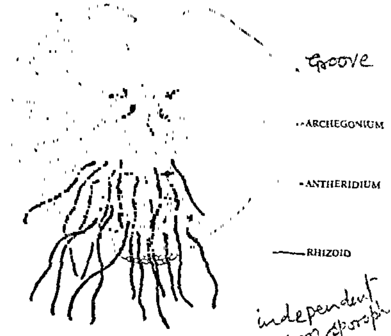


FIG. 147. Prothallus of fern.

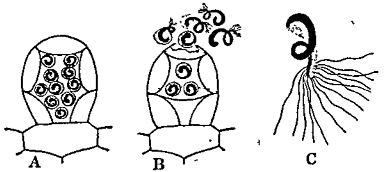
independent from sporophyte

At first it gives rise to a short green filament resembling an alga or moss protonema. Subsequently by further division of cells it produces a small green flat heart-shaped body, about 8 mm. across; this

is known as the **prothallus**. At maturity the prothallus is a thin flat [illegible]

layers of cells in thickness. Unicellular, hairy processes, called rhizoids, come out from the undersurface of the prothallus; these fix the prothallus to the soil and absorb water and mineral salts. For reproduction highly specialized structures are produced on the undersurface of the prothallus; these are the **antheridia** or male organs and the **archegonia** or female organs. The former develop amongst the rhizoids and the latter near the groove.

The **antheridium** (FIG. 148 *A-B*) is a spherical or oval body consisting of a wall or jacket with 1 or 2 caps or cover cells at the apex and



Fern. FIG. 148. Antheridium. *A*, a young one with antherozoid mother cells; *B*, a mature one after bursting; and *C*, an antherozoid.

a number of antherozoid mother cells (20-50). Each mother cell develops a single, spirally coiled **antherozoid** (or spermatozoid) or male gamete consisting mostly of nuclear material. It bears a number of fine threads, called cilia, near its tip (FIG. 148*C*).

The **archegonium** (FIG. 149) is a flask-shaped body. The swollen basal portion is known as the **venter**, and the slender tube-like upper

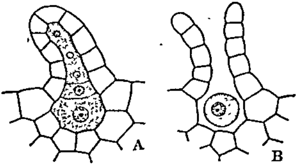


FIG. 149. Archegonium. *A*, a young one; and *B*, a mature one ready for fertilization. Note the venter and the neck.

portion as the **neck**. The venter encloses a single large cell—the egg-cell or ovum with a distinct egg nucleus in it, and slightly higher up a ventral canal cell. The neck consists of a longitudinal canal with

a few neck canal cells in a row, and a wall made of four vertical rows of cells. The neck is short and curved, and the venter lies embedded partially or completely, in the prothallus. All the canal cells disintegrate into mucilage before fertilization, which forces open the lid of the archegonium.

Fertilization. When the antheridium matures it bursts and the antherozoids are liberated. They swim about in water by means of their cilia. As the archegonium matures it secretes mucilage and malic acid. Attracted by these substances a large number of antherozoids swim to the archegonium, enter it through the neck and pass down into the venter. They quickly vibrate around the egg-cell and one of them soon fuses with the egg-nucleus. After this fusion (fertilization) the rest of the antherozoids die out. The fertilized ovum clothes itself with a cell-wall and becomes the oospore. The oospore divides and gives rise to an embryo. The embryo grows up into a young sporophyte (with a green leaf and a root) still attached to the prothallus (FIG. 150). With the penetration of the root into the soil and decay of the prothallus the young sporophyte develops into a fern plant as an independent body.

FIG. 150. Prothallus of fern with young sporophyte.

Alternation of Generations (FIG. 151). The fern plant, as its life-history shows, passes through two stages or generations. The plant itself is the sporophyte, and the prothallus the gametophyte. The sporophyte or the fern plant reproduces asexually by spores and gives rise to the gametophyte or the prothallus, and the latter reproduces sexually by gametes (antherozoid *and ovum*) *and gives rise to the* sporophyte or the fern plant. Thus the two generations regularly alternate with each other. In the life-history of fern $2n$ chromosomes are met with for the first time in the oospore and, therefore, this is the beginning of the sporophytic generation, and all the stages from the oospore to the spore mother cells represent the sporophytic or asexual generation of fern. Reduction of chromosomes to n number takes place in the formation of the spores from the spore mother cells and, therefore, they (spores) represent the beginning of the gametophytic generation, and all the stages from the spores to the gametes (antherozoid and ovum) constitute the gametophytic or sexual generation. It is noticeable that the sporophyte (fern plant)

has already reached a high degree of development and complexity, and with the formation of roots and green leaves with chloroplasts,

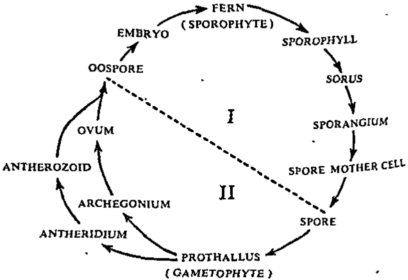


FIG. 151.
tions. *I*, sp

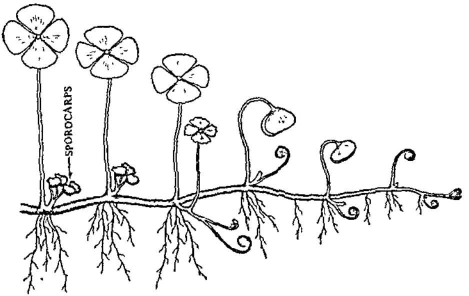
of it is very insignificant.

5. *MARSILEA* (65 sp.)

Marsilea (FIG. 152) is one of the three genera of *Marsileaceae*. It
k or a ditch,
rsilea quadri-
e plant body
consists of a slender prostrate dichotomously branched rhizome with distinct nodes and internodes, commonly rooting at the nodes and giving of
when yo
a long or
manner.
by smaller veins. Growth of the stem is due to an apical tetrahedral meristematic cell.

Sporophyte. *Marsilea* plant is the sporophyte bearing two kinds of spores, i.e. it is heterosporous. Special structures, called sporocarps, are seen to grow, in small groups of 2-5, sometimes singly from the base of the petiole or a little above it as a segment of it (interpreted

as modified fertile leaf-segment or entire leaf). Sporocarps develop only when the water recedes and the soil tends to dry up, and each

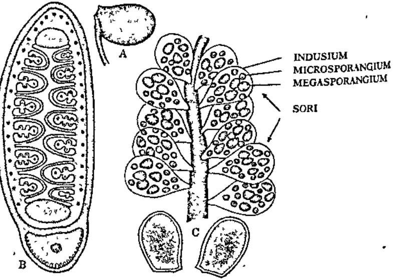


Marsilea. FIG. 152. A plant with sporocarps.

is provided with a long or short stalk and has a very hard outer covering, when mature. In structure it is more or less bean-shaped (FIG. 153) and is about 8×6 mm. in size. Each half of the sporocarp has distinct forked venation alternating with that of the other half. The sporocarp (FIG. 153*B*) contains within it usually 14-20 sori, each in a cavity, arranged in two rows on a receptacle; the sori develop in basipetal order. Each sorus is covered by an indusium, two layers of cells thick. The sporangia at the apex of the receptacle are megasporangia and those lower down are microsporangia. The sporangium wall in each case is made of a single layer of cells. The sori are attached to a tissue which swells considerably in water and becomes gelatinous. In the early stages of development both kinds of sporangia form 8 or 16 sporocytes or spore mother cells which on reduction division produce 32 or 64 spores. But in the case of microsporangium all the microspores are functional, though very minute in size; while in the case of megasporangium only one megaspore grows larger in size and is functional; others degenerate.

With the development of the sporangia a stony layer is formed on the outer surface of the sporocarp. The resisting power of the sporocarp and the longevity of the spores are remarkable; spores have been seen to germinate even after many years of desiccation. If the sporocarp be cracked at the edge and kept in water for half an hour or so it is seen that the gelatinized inner wall of the sporocarp pushes out of it in the form of a long gelatinous ring (sorophore)

with the sori attached to it in an alternating manner[1] (FIG. 153C). In nature, however, the sporocarp takes at least 2 or 3 years for the decay of its stony layer. Thereafter the spores are liberated on the



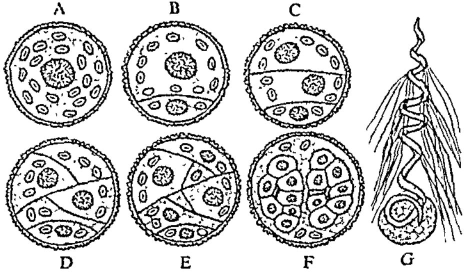
conversion of the indusium and the sporangium walls into mucilage. If the mucilaginous ring be left in water the development of the male and female gametophytes may be seen on the following day or the day after.

Gametophytes. The spores germinate very quickly, the microspore [illegible] giving rise to the mal[illegible] gametophyte. Within [illegible] tophyte is complete, [illegible] in development.

The male gametophyte (FIG. 154 *A-F*) is endosporous developing within the microspore, as in *Selaginella*. A cell cut off on one side is the prothallus cell, while the remaining cell of the gametophyte divides into two halves; each half is an antheridium. After further divisions two primary spermatogenous cells are formed surrounded by a jacket layer. Each cell then produces 16 *antherozoid mother cells*. Each mother cell is metamorphosed into an antherozoid

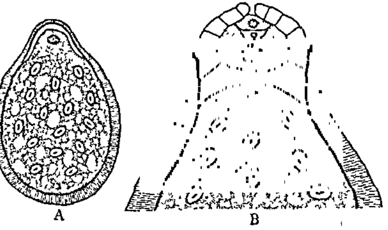
[1] The sporocarp may also be split open with a sharp scalpel into two valves, the contents gently scooped out and spread on a slide in water, covered with a cover-glass, and lightly tapped.

(FIG. 154*G*). This is much coiled, corkscrew-like and multiciliate, with a mucilaginous vesicle containing some food.



Marsilea. FIG. 154. *A-F*, development of the male gametophyte; *G*, an antherozoid. *Redrawn after Fig. 252 in* Plant Morphology *by A. W. Haupt by permission of McGraw-Hill Book Company. Copyright 1953.*

The female gametophyte (FIG. 155 *A-B*) consists of an archegonium protruding out of the megaspore-coat at its apex, while the rest of the gametophyte without any cellular differentiation is a food



... and the sterile jacket.

reservoir. The archegonium consists of (*a*) a venter with a comparatively large egg and a small ventral canal cell, (*b*) a short neck with a neck canal cell, and (*c*) a sterile jacket of cells. Surrounding the

female gametophyte there is a broad gelatinous envelope, which has a funnel-shaped portion converging to the archegonium.

Fertilization. Fertilization takes place almost immediately after the gametophytes are formed. Innumerable antherozoids swarm around the archegonium, many of them swim into the gelatinous envelope on the archegonium side, and some of them pass down the neck. Finally, however, one antherozoid fuses with the egg-nucleus.

Embryo. After fertilization the embryo is quickly formed. The oospore divides and re-divides and the cells are arranged in four segments. The two segments, outer and inner, on one side give rise to the stem and the first leaf (cotyledon), while the remaining two segments, inner and outer, on the other side give rise to the foot and the root. The adjoining cells of the gametophyte form a cap-like structure or calyptra around the developing embryo.

Internal Structure of *Marsilea* Rhizome (FIG. 156). (1) **Epidermis** lies externally as a single layer. (2) **Cortex** consists of usually two layers of thin-walled parenchyma

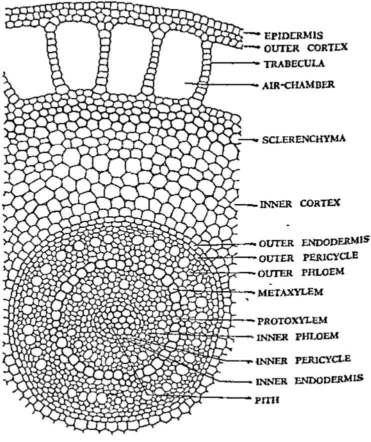


FIG. 156. Rhizome of *Marsilea* in transection. (Amphiphloic siphonostele)

internal to the epidermis, a ring of fairly big air-cavities traversed by trabeculae, one to three layers of thick-walled lignified cells, and internally several layers of thin-walled parenchyma containing starch grains. (3) Stele is an *amphiphloic siphonostele* with pith in the centre. It is bounded both externally and internally by phloem, pericycle and endodermis which evidently occur twice. In the middle xylem occurs as a ring with more or less distinct protoxylem and metaxylem, and consists of thick-walled tracheids. (4) Pith occupies the central portion and is parenchymatous or sclerenchymatous (growing in water or on mud).

6. *ISOETES* (*over 60 sp.*)

Isoetes (FIG. 157A), commonly called quillwort, is the only genus of *Isoetaceae*. Species of this genus are mostly confined to temperate regions. *Isoetes coromandeliana*, however, is found in India. *Isoetes* commonly grows at the edge of a tank, ditch, stream or in a shallow pool of water, partly or completely submerged in water and looks like a tuft of grass. Growth in length of the stem is due to the activity of the apical meristematic cells.

Sporophyte. *Isoetes* plant is the sporophyte bearing two kinds of

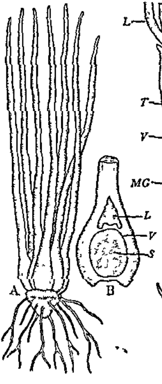


FIG. 157.

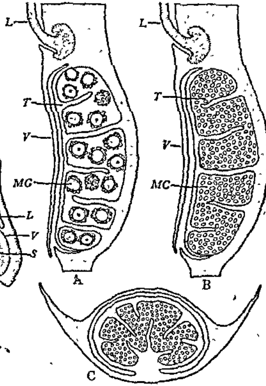
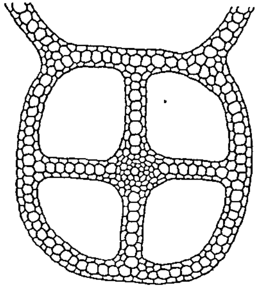


FIG 158

Isoetes. FIG. 157. *A*, a plant; *B*, leaf-base (inner ... FIG. 158. *A*, ...rangium in ...n. *L*, ligule; ... *MG*, megaspore; *MC*,

sporangia and spores (micro- and mega-) on the same plant, i.e. it is heterosporous and monoecious. It consists of a short 2- or 3-lobed corm-like stem, a rosette of linear leaves arising from the upper surface, and many slender often dichotomously branched roots developing from the lower sides. Each leaf is provided with a persistent ligule (FIG. 157*B*), as in *Selaginella*, and internally there are some longitudinal air-chambers (FIG. 159). Leaf-base is spoon-shaped and swollen owing to the development of a large sporangium on its inner concave surface just below the ligule (FIG. 157*B*). Most of the leaves except the central ones are potential sporophylls, the outer ones bearing megasporangia (FIG. 158*A*) and the inner ones microsporangia (FIG. 158 *B-C*.) Each sporangium is wholly or partially covered over by a membranous flap known as the velum which arises below the ligule (FIGS. 157*B* & 158) and grows downwards The sporangium (micro- or mega-) is traversed by strands of cells, called the **trabeculae** (FIG. 158), which may be complete or incomplete. The two kinds of sporangia cannot be distinguished when they are young. When mature the microsporangium is seen to produce a very large number of minute microspores (150,000-1,000,000), and the megasporangium only a limited number of large megaspores (50-300). The megaspores are variously sculptured. Both microspores and megaspores are formed in tetrads, as usual.



Isoetes. FIG. 159. Leaf in transection.

Gametophytes. Spores are liberated after the decay of the sporangium wall. The microspore gives rise to the male gametophyte, and the megaspore to the female gametophyte. The **male gametophyte** (FIG. 160 *A-D*) remains enclosed within the microspore coat, as in *Selaginella*, and consists of (*a*) a prothallus cell, (*b*) an antheridium of four antherozoid mother cells, and (*c*) a sterile jacket of four cells. Each antherozoid mother cell gives rise to a single large coiled multiciliate antherozoid (FIG. 160*E*). Thus altogether four antherozoids are produced by each male gametophyte, the lowest among all pteridophytes. The wall of the microspore bursts and the antherozoids are liberated. The **female gametophyte** (FIG. 161*A*) develops

inside the megaspore and does not protrude but, as in *Selanginella*, a tri-radiate fissure is formed in the megaspore wall exposing the rhizoids and the archegonia; the latter vary in number from one to many. The megaspore nucleus lying at one end begins to divide

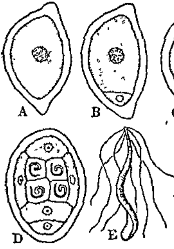


FIG. 160

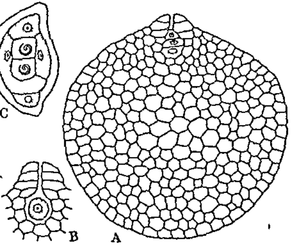


FIG. 161

Isoetes FIG. 160. [illegible]
E, an antherozoid. [illegible]
Redrawn after Figs. [illegible]
permission of [illegible]

repeatedly and gradually the whole of the female gametophyte becomes cellular. This is the female prothallus, and archegonia develop in it one after another in the first-formed region of the prothallus, if the previous one is not fertilized. The archegonium (FIG. 161*B*) consists of (*a*) a neck with 3 or 4 tiers of cells, (*b*) a neck canal cell (sometimes binucleate), (*c*) a venter with a ventral canal cell, and (*d*) a conspicuous egg.

Embryo. The fertilized egg (oospore) divides transversely. The lower cell after further repeated divisions gives rise to a massive foot. The upper cell divides vertically, and one of the two cells thus formed gives rise to the first leaf (cotyledon), and the other cell to the root. The stem arises later.

PART VI *Gymnosperms*

Chapter 1 GENERAL DESCRIPTION

Spermatophytes (or 'seed' plants) or phanerogams (or 'flowering' plants) are divided into two sub-divisions—angiosperms (*angeion*, case; *sperma*, seed) and gymnosperms (*gymnos*, naked). Gymnosperms are closely related to the higher cryptogams on the one hand and to the angiosperms on the other, and thus they form an intermediate group between the two. It should be noted that lower gymnosperms like cycads have greater affinities with the higher cryptogams, while the higher gymnosperms—Coniferales and Gnetales—are closer to the angiosperms. Salient points of resemblances and differences are given below. Gymnosperms number about 700 species.

GYMNOSPERMS AND HIGHER CRYPTOGAMS

Resemblances. (1) Identical nature of general life-history in both with, of course, structural differences; both the groups show a regular alternation of generations with gradual reduction and loss of independence of gametophyte from higher cryptogams to gymnosperms, and gradual increase in the complexity of the sporophyte.

(2) Differentiation of the plant body into root, stem and leaves.

(3) Compound nature of leaves and circinate vernation, as in earlier gymnosperms (cycads).

(4) Xylem of the vascular bundle with only tracheids (and no vessels except in Gnetales) and phloem without companion cells

in the form of cones (strobili).

(6) Development of the gametophyte within the spore-coat as a dependent body (partially endosporous in *Selaginella* but completely endosporous in gymnosperms) for advantages of food supply and adequate protection by the sporophyte.

(7) Development of ciliate spermatozoids in lower gymnosperms (cycads), as in cryptogams.

(8) Retention of the megaspore within the megasporangium (permanently in gymnosperms but for a short period only in *Selaginella*) and the development of the archegonia in the female gametophyte.

(9) Formation of the suspensor in gymnosperms during the stages of embryo development, as in *Selaginella*.

Differences. (1) Development of the ovule (and later the seed) in gymnosperms makes a fundamental difference between them and the cryptogams. The ovule

and the seed are characteristic of all gymnosperms, while they are altogether absent in cryptogams.

(2) Formation of the pollen-tube in gymnosperms is another special feature which is conspicuous by its absence in cryptogams. The pollen-tube carries the non-motile male gametes to the archegonium in most of the gymnosperms, while in all cryptogams the motile spermatozoids by themselves swim to the archegonium in a drop of water. In *Cycas*, however, the pollen-tube is a sucking organ (haustorium) and not a sperm-carrier.

(3) *The megasporangium of the gymnosperm is not shed before fertilization and maturity*; further it is provided with a new structure in the form of a coat—the integument. The megasporangium covered by the integument is the ovule. The ovule is altogether absent in cryptogams.

(4) The megaspore of the gymnosperm *remains permanently enclosed within* the megasporangium, and the female gametophyte is also completely endosporous (partially endosporous in *Selaginella*) and is consequently dependent on the mother sporophyte for its nourishment. The embryo also remains enclosed within the megasporangium and is nourished by it.

[illegible]

takes place in higher gymnosperms, as in *Gnetum*,—a condition more akin to angiosperms.

(7) Presence of the cambium in gymnosperms leading to secondary growth in thickness, and absence of it in cryptogams with no secondary growth. Besides, tracheids with circular pits and those with sclariform markings are characteristic of gymnosperms and higher cryptogams respectively.

GYMNOSPERMS AND ANGIOSPERMS

Resemblances. (1) The plant body is differentiated into distinct root and shoot, the latter with copious branches and leaves, however small they may be. In habit the plants of both groups may be shrubs and trees, with preponderance of angiospermic herbs.

(2) Vascular system is well developed in both, with xylem and phloem (note, however, their differences, as given at p. 540).

(3) Flowers are developed in both cases for reproduction. But gymnospermic flowers *are primitive in nature and simple in construction* and are always unisexual and without perianth. Angiospermic flowers, however, are more advanced often *with both sepals and* petals, and are unisexual or bisexual. Gymnospermic flowers are pollinated through the agency of air-currents only, while angiospermic *flowers are pollinated through* various agencies, particularly insects.

(4) Microspore or pollen grain grows into a pollen-tube which carries the male gametes to a position close to the egg-cell or ovum for the purpose of fertilization. In *Cycas*, however, the pollen-tube is branched penetrating into the nucellus *and acts as a sucking organ* (haustorium) and not as a sperm-carrier.

(5) The megaspore remains permanently enclosed in the megasporangium (nucellus of the ovule) and it germinates into the female gametophyte or embryo-sac (reduced prothallus) within the megasporangium.

(6) *The megasporangium remains enclosed by the integument* (*1 in gymnosperms and usually 2 in angiosperms*) giving rise to a more complicated structure—the ovule (and later the seed) for better protection of the embryo.

ovule and the following factors are responsible for its development.

(1) Heterospory and differentiation of sporophylls and sporangia are the initial factors, as we find in *Selaginella*, leading towards seed production in the future.

(2) Retention of the megaspore within the megasporangium (nucellus of the ovule) and its germination into the female gametophyte (embryo-sac) within the megasporangium so that the female gametophyte becomes completely *endosporous*; it is partially endosporous in *Selaginella*.

(3) Enclosure of the megasporangium and the female gametophyte within a new structure, *i.e. the integument*,—the whole complex body so formed being known as the *ovule*. This ovule after fertilization and maturity gives rise to the seed.

(4) Attachment of the megasporangium (and the ovule) to the megasporophyll till after its development into the seed.

(5) Development of the young sporophyte (embryo) within the tissue of the megasporangium (nucellus) which belongs to the mother sporophyte, ensuring better feeding and greater protection.

(6) Development of the pollen-tube for facility of fertilization under the new condition of ovule formation.

It is thus evident that the seed of the gymnosperm is a complex structure with three generations locked up in it: (1) the seed-coat or testa representing the parent sporophyte (old generation), (2) the female gametophyte representing the present generation, and (3) the embryo representing the new sporophyte (future generation).

Classification. Gymnosperms comprise 7 orders, of which 3 have become extinct, and the remaining 4 have living representatives. The orders are: (1) Cycadofilicales or seed ferns or pteridosperms (extinct), (2) Bennettitales (extinct), (3) Cycadales (represented by the family *Cycadaceae* with 9 genera and 100 species), (4) Cordaitales (extinct), (5) Ginkgoales (represented by the family *Ginkgoaceae* with 1 genus and 1 species (cultivated in China and Japan), (6) Coniferales (largest order represented by 6 families with 41 genera and over 500 species) and (7) Gnetales (represented by the family *Gnetaceae* with 3 genera and about 71 species). An outline of classification is given in the following schedule:

Order 1	Cycadofilicales	— fossils only,	e.g. *Lyginopteris*
Order 2	Bennettitales	— fossils only,	e.g. *Cycadeoidea*
Order 3	Cycadales	— *Cycadaceae*,	e.g. cycad (*Cycas*)
Order 4	Cordaitales	— fossils only,	e.g. *Cordaites*
Order 5	Ginkgoales	— *Ginkgoaceae*,	e.g. *Ginkgo*
Order 6	Coniferales	— *Abietaceae*,	e.g. pine (*Pinus*)
Order 7	Gnetales	— *Gnetaceae*,	e.g. *Gnetum*

Origin and Evolution of Gymnosperms. Evidence from fossil records goes to show that gymnosperms originated from the oldest and the most primitive group of

ferns—the Psilophytales—which flourished during the Devonian period of the

carboniferous period. Towards the close of the Palaeozoic or very early Mesozoic both the groups became extinct. The four groups of Gymnosperms (leaving out Gnetales), viz. Bennettitales, Cycadales, Ginkgoales and Coniferales, which evolved independently from the two Palaeozoic extinct groups formed the dominant vegetation of the earth during the mid-mesozoic period. They, however,

tales originated from the Cycadofilicales, flourished and died during the same age. The Cycadales which also originated from the Cycadofilicales, but independently of Bennettitales, have left some living representatives (about 100 species) Ginkgoales and Coniferales originated, independently of one another, from the Cordaitales; but the former has left only one living representative (*Ginkgo biloba*) —a large tree in western China (now widely cultivated), and the latter over 500 living representatives (the biggest group of living gymnosperms). The remaining group of gymnosperms, viz. the Gnetales, is regarded as the most recent and the highest group with 3 genera and about 71 species. The fossil records of the Gnetales are rare and fragmentary, and not found earlier than the Tertiary. Evidently the group is of recent origin

Chapter 2 CYCADALES

The family *Cycadaceae* (commonly called cycads) comprises 9 genera with about 100 species. The genus *Cycas* is represented in India by a few species, of which *C. revoluta* and *C. circinalis* are fairly common in the hills and often planted in gardens; both yield a kind of sago. *C. pectinata* is common in the low hills of Assam.

CYCAS (*20 sp.*)

The stem of cycad (*Cycas*; FIG. 1) is unbranched, erect, stout and palm-like, with a crown of pinnate leaves arranged spirally round the apex. Besides, there are small, dry, scale-like leaves alternating with the green pinnate leaves. Vernation (ptyxis) of the leaf is *circinate* like

two

apex of the stem

a sympodium). In *Cycas pectinata* the male cone may be as big as

half a metre in length. The male cone consists of a collection of stamens or microsporophylls arranged spirally round the axis. Each sporophyll (FIG. 3C) is in the form of a scale, narrowed below and broadened above. It bears on its under-surface several pollen-sacs or microsporangia grouped in sori. There are usually 2 to 6 pollen-sacs in each sorus. In each pollen-sac there are numerous pollen grains or microspores. Each microspore before it sheds from the microsporangium or pollen-sac produces within it a male prothallus (FIG 5A). This is the male gametophyte. It consists of a vegetative (prothallus) cell, a generative cell and a tube cell.

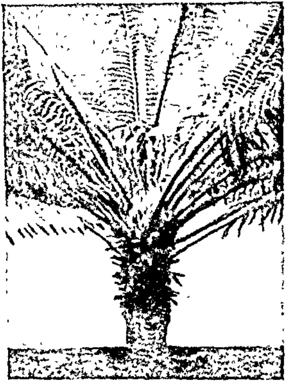
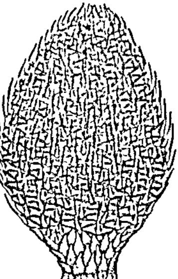


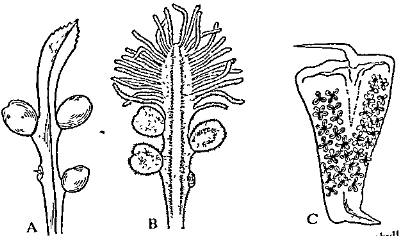
FIG. 1. A female plant of *Cycas circinalis* with carpels.

In *Cycas* there is no proper female flower; the plant bears near its apex a rosette of carpels or megasporophylls (FIG. 3 *A-B*) which do not form a cone but are arranged alternating with the leaves. They are usually 15 to 30 cm. long, flattened or bent over like a hood, and often dilated above. In many species they are covered all over with soft brownish hairs. The margin may be entire, crenate or pectinate (pinnately divided). Ovules, usually 2-3 pairs, sometimes up to 5 pairs, are borne in an alternate or opposite manner in notches on either side of the stalk. These are commonly oval and large, sometimes very large as in *C. circinalis* where they grow up to 6 cm. In gymnosperms the carpel is always open, i e. it does not close up, as in angiosperms, to form the ovary, style and stigma, and the ovules are borne, freely exposed, on the two margins of the carpel. The ovule (FIG. 4*A*) grows considerably even before fertilization. It consists of a single thick integument and a nucellus or megasporangium fused practically throughout with the integument. The integument has an apical opening—the micropyle—and consists of three layers—a middle stony layer and a fleshy layer on either side. The inner layer

merges into the nucellus lower down. Within the nucellus of the ovule a megaspore mother cell is produced which divides to form a row of four megaspores. Only one megaspore is functional; while the others disintegrate. The functional megaspore divides rapidly and gives rise to a cellular mass of tissue within it; this is the female prothallus or gametophyte (designated as the endosperm). *The prothallus is completely endosporous.* The development of the gametophyte begins with repeated free nuclear divisions. The nuclei so formed are pushed towards the periphery by the appearance of an enlarging central vacuole. Cell-walls then develop round the nuclei from the peripheral region towards the centre. The fully developed gametophyte thus becomes cellular and large occupying the major part of the nucellus, with two distinct regions in it—a region of smaller cells towards the upper end, and a region of larger cells, nutritive in function, with sugar at first and



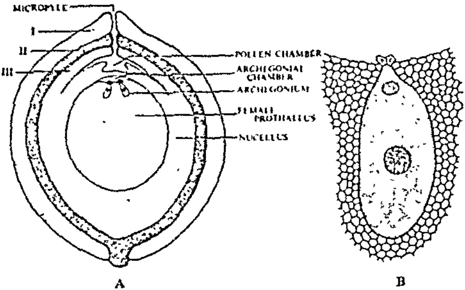
Cycas. FIG. 2. A male cone of *Cycas pectinata* consisting of innumerable microsporophylls arranged round the stout axis.



Cycas. Carpels and Stamen. FIG. 3 *A*, a carpel or megasporophyll of *Cycas circinalis*; *B*, the same of *Cycas revoluta*; *C*, a stamen or microsporophyll of *Cycas pectinata* with numerous pollen-sacs or microsporangia on the undersurface (slightly oblique view).

starch later. The endosperm grows quickly after fertilization, invades the nucellus, and forms the major part of the seed. The small-celled

free egg-nucleus. The ventral canal cell is represented only by a nucleus which, however, soon becomes disorganized. The central

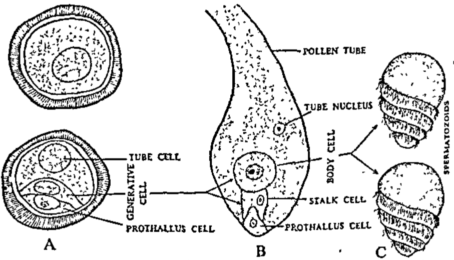


Cycas. FIG. 4. *A*, ovule in longitudinal section; *I*, *II* and *III*, outer, middle (stony) and inner layers of the integument; *B*, an archegonium.

cell is invested by a special layer of cells, called the jacket, which is pitted. Through the pits food materials enter the central cell. Just below the micropyle a chamber or cavity is formed due to the breaking down of some of the nucellus cells. This cavity is called the pollen chamber. Just below this another chamber is formed in the prothallus. This is the archegonial chamber.

Pollination and Fertilization. Pollen grains are carried by the wind. They fall on the micropyle and get bathed in the mucilage secreted by the latter; as the mucilage dries up the pollen grains are drawn into the pollen chamber. The pollen grain divides and forms (*a*) a small prothallus cell (male gametophyte) on one side, (*b*) a generative cell, and (*c*) a tube cell. The tube cell elongates into a long branched pollen-tube (FIG. 5B) which penetrates into the archegonial chamber, the membrane between the two chambers having broken down. The pollen-tube of *Cycas* is a sucking organ (haustorium) absorbing food from the nucellus, and is not a sperm-carrier. The generative cell divides into two—the stalk cell and the body cell. The stalk cell is sterile and the body cell divides into two remarkably large top-shaped multiciliate male gametes (spermatozoids; FIG. 5C). The pollen-tube bursts at the apex and the spermatozoids are set free.

They swim to the archegonium by the vibration of their cilia and enter into the egg-cell. The male nucleus slips out of its cytoplasmic



Cycas. FIG. 5. *A, top,* a pollen grain or microspore; *bottom,* male prothallus; *B,* pollen-tube (a portion); *C,* two spermatozoids.

sheath, moves towards the egg-nucleus, and *finally penetrates* into it. Fertilization is thus effected.

Development of the Embryo. After fertilization the egg-nucleus divides 8 or 10 times by free nuclear divisions. As a result a large number of free nuclei (without cell-walls) appear in the enlarged egg. A central vacuole is formed which quickly enlarges, and as a consequence the *free nuclei are pushed towards the periphery of the egg.* Later cell-walls begin to be formed round the nuclei. A tissue thus appears which soon fills up the who
the base of the egg constitut
form a large food reservoir

of the female gametophyte. The embryo, as it takes shape, becomes differentiated into a radicle, a plumule and a pair of cotyledons. Although there are a few archegonia, only one embryo matures in a seed.

Seed. After fertilization the ovule as a whole grows into the seed. The seed is large, globose or ovoid, 2.5-5 cm. across, usually orange *or red in colour. The mature seed bears only one embryo* with *two* cotyledons (in all cycads) lying embedded in copious endosperm which again is surrounded by a stony integument. The endosperm stores a considerable quantity of food to be utilized by the embryo while the seed germinates.

Internal Structure of Cycad Leaf (FIG. 6). (1) Epidermis—the upper with very thick cuticle, while the lower with comparatively thin cuticle but with a large number of sunken stomata, each arched over by epidermal outgrowth. (2) Hypodermis—the upper is highly thickened, while the lower comparatively thin. (3) Mesophyll differentiated into upper distinct palisade parenchyma and lower spongy parenchyma. In between the two there is a tissue of long colourless cells forming the transfusion tissue or conducting channel which runs horizontally from the vascular bundle (mid-rib) to near the margin of the leaf. Veins being absent in cycad leaf food and water are conducted to the leaf-blade through the

FIG. 6. *Cycas* leaf in transection.

transfusion tissue. (4) Vascular bundle with xylem on the upper side and phloem on the lower. Xylem is mesarch, i.e. protoxylem lies in the middle of xylem; towards the upper side xylem is well developed and forms centripetal xylem (with distinct protoxylem and metaxylem), while towards the lower side, lying in the parenchyma of the bundle, small vascular strands detached from the centripetal xylem form centrifugal xylem. The vascular bundle is more or less completely surrounded by a sheath (bundle sheath). Some small thick-walled cells and some clusters of crystals may be seen here and there in the section.

Chapter 3 CONIFERALES

Coniferales (coniferae or conifers) constitute the largest order among the gymnosperms and comprise six families, e.g. *Abietaceae*, *Taxaceae*, *Cupressaceae*, etc., which are represented by 41 genera and over 500 species. They grow mostly in cold climates and at high altitudes in the hills, and are evergreen trees or shrubs. *Taxaceae* is represented by 4 genera and 18 species, of which yew (*Taxus*) is the typical genus, and *Abietaceae* is represented by 9 genera and about 230 species, of which pine (*Pinus*), fir (*Abies*), Atlantic cedar (*Cedrus atlantica*), Himalayan deodar (*Cedrus deodara*), etc., are some of the genera. *Pinus* is, of course, the typical genus of *Abietaceae*.

PINUS (*90 sp.*)

Pine (*Pinus*; FIGS. 9-10) is a tall tree with a well-developed tap root and numerous aerial branches. Common species of *Pinus* are *P. khasya*, *P. sylvestris*, *P. longifolia*, *P. excelsa*, etc. Leaves of *Pinus* are of two kinds—long green needle-like foliage leaves and small brown scaly leaves. Shoots are also of two kinds—long (of unlimited growth) and dwarf (of limited growth). (See caption of FIG. 9.)

Internal Structure of the Young Stem. This resembles the dicotyledonous stem in many respects. The general arrangement of the various tissues from the circumference to the centre is the same It differs, however, from the latter in having a large number of resin-ducts filled with brownish contents, i.e. resin. These ducts are to be seen distributed almost throughout the stem. The epidermis has an irregular outline. Endodermis and pericycle are like those of the dicotyledonous stem, but the pericycle,contains no sclerenchyma. The vascular bundles are not wedge-shaped, as in the dicotyledons. Phloem consists of sieve-tubes and phloem parenchyma, but no companion cells. Protoxylem consists of annular and spiral tracheids which are irregularly disposed towards the centre. Metaxylem consists exclusively of tracheids with bordered pits. The tracheids are arranged in radial rows as seen in a transverse section of the stem. The pits of the coniferous wood are large and mostly restricted to the radial walls; while in angiosperms they are much smaller but more numerous, and are not confined to particular walls. There are no true vessels in the coniferous stem.

(1) **Epidermis.** A single layer with a very thick cuticle, and an irregular outline. (2) **Sclerenchyma.** Sometimes a few patches of sclerenchyma occur here and there below the epidermis. (3) **Cortex.** Many layers of more or less rounded cells, with conspicuous resin-ducts lying embedded in the cortex. (4) **Endodermis.** A single layer lying internal to the cortex, but not well marked off from the latter. (5) **Pericycle** is parenchymatous only; there is no sclerenchyma in it. (6) **Medullary Rays.** These run from the pith outwards between the vascular bundles. (7) **Pith.** There is a well-defined pith, consisting of a mass of parenchymatous cells. A few resin-ducts are also present in the pith. (8) **Vascular Bundles.** These are collateral and open, and arranged in a ring, as in the stems of dicotyledons. Each bundle

onsists of phloem, cambium and xylem. (*a*) **Phloem** consists of sieve-tubes and hloem parenchyma, but no companion cells. It lies on the outer side of the undle. (*b*) **Cambium.** A few layers of thin-walled, rectangular cells lying in etween xylem and phloem. (*c*) **Xylem** consists exclusively of tracheids; there re no true vessels in the wood. Resin-ducts are also present here. Protoxylem es towards the centre and consists of a few annular and spiral tracheids which re not disposed in any regular order. Metaxylem lies towards the cambium, and onsists of tracheids with bordered pits which develop on the radial walls. These racheids are roughly four-sided and are arranged in definite rows.

Secondary Growth in Thickness of the Stem (FIG. 7). The secondary growth in a coniferous (pine) stem takes place in exactly the same way as in a dicotyledonous

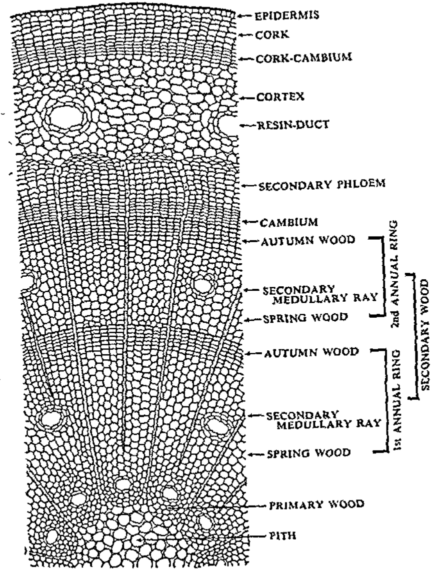


FIG. 7. A two-year old pine stem in transection (a sector).

stem. The following points may, however, be mentioned here, showing slight differences between the two.

The coniferous (pine) stem is characterized by the presence of conspicuous resin-ducts which are distributed throughout almost all the stem. The secondary wood consists exclusively of tracheids with numerous bordered pits on their radial walls. As in the dicotyledonous stem, there are distinct annual rings, consisting of the autumn wood and the spring wood; the former consists of narrow and thick-walled tracheids, and the latter of wider and thinner-walled tracheids. The secondary medullary rays are usually one layer of cells in thickness and a few in height. The phloem portion of the medullary ray consists of middle layers of starch-containing cells, called *starch cells*, and upper and lower layers of protein-containing cells, called *albuminous cells*; the xylem portion of the same consists of similar *starch cells* in the middle, and empty cells with bordered pits, called *tracheidal cells*, in the upper and lower layers. Vessels or fibres are absent.

Internal Structure of the Pine Needle (FIG. 8). (1) **Epidermis**—a single layer of very thick-walled cells with a strong cuticle; the cell-cavity is nearly obliterated. There are stomata sunken to some extent in this layer, each stoma opening internally into a respiratory cavity. (2) **Sclerenchyma** occurs internal to the epidermis in 1, 2 or 3 layers interrupted by the stomata. This tissue is deeper at the ridges.

FIG. 8. Pine needle (leaf) in transection.

(3) **Mesophyll** consists of large thin-walled polygonal or irregular cells containing abundant chloroplasts. There are peg-like projections of the cell-walls into the cell-cavity. In the mesophyll there are some resin-ducts here and there. Each resin-duct is surrounded by a layer (epithelium) of thin-walled cells. (4) **Endodermis** occurs as a conspicuous layer of large barrel-shaped cells. (5) **Pericycle**

lies internal to the endodermis and is a many-layered tissue. It consists of some parenchyma, often some sclerenchyma, particularly on the phloem side, and transfusion tissue. Transfusion tissue consists of (*a*) *albuminous cells* which are parenchymatous in nature, living and rich in protein and starch, and (*b*) *tracheidal cells* which are thin-walled elongated dead cells, but provided with bordered pits like tracheids. Albuminous cells serve to conduct food from the mesophyll to the phloem, and tracheidal cells to conduct water and mineral salts from the xylem to the mesophyll. (6) **Vascular bundles** are two in number and collateral (closed). Xylem consisting of rows of tracheids lies towards the angular side of the leaf, and phloem consisting of sieve-tubes lies towards the convex side.

Pinus, like all other gymnosperms, is the **sporophyte**. It bears two kinds of sporophylls—**microsporophylls** and **megasporophylls** (cf. *Selaginella*). These are collected together at the apex of the shoot into two separate cones, called the flowers. Cones always develop on the shoots of the current year, the male ones (FIG. 9) near their apex grouped together in spikes, and the female ones (FIG. 10) lower down, either solitary or in a whorl. Flowers have no perianth.

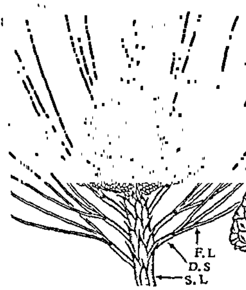


FIG. 9.

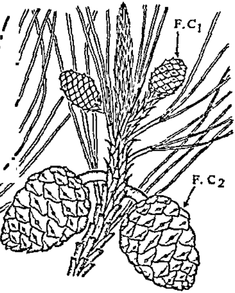
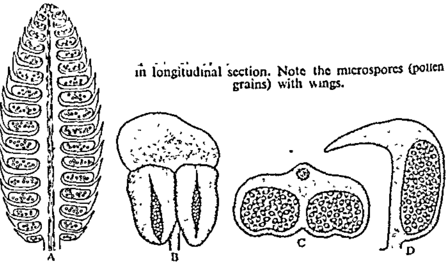


FIG. 10.

third year cone see FIG. 17A), and the rest as in FIG. 9.

Male Cone (FIGS. 9 & 11A). The male-cone bears a number of spirally arranged microsporophylls or stamens. Each microsporophyll

(FIG. 11*B*) is differentiated into a stalk (filament) and a terminal leafy expansion (anther). It bears on its undersurface two pouch-like



in longitudinal section. Note the microspores (pollen grains) with wings.

microsporangia or pollen-sacs (FIG. 11 *B-D*). In some conifers these may be as many as 15. Each pollen-sac is filled up with numerous pollen grains or microspores. Each pollen grain has two coats—outer

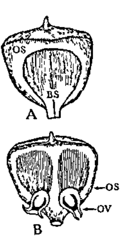


FIG. 12

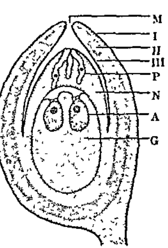


FIG. 13

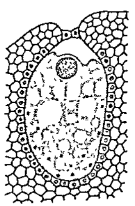
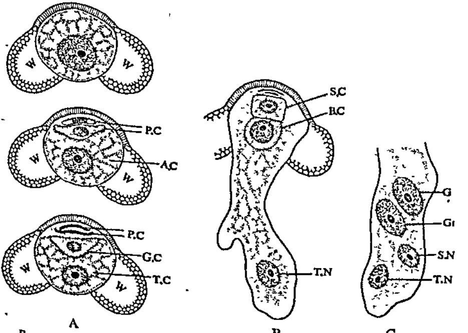


FIG. 14

and inner, respectively known as *exine* and *intine*. The exine forms two wings (FIG. 15*A*) on the two sides. A huge quantity of pollen is produced for pollination to be brought about by wind.

Female Cone (FIGS. 10 & 16*A*). Each female cone consists of a short axis round which a number of small dry brownish scales, slightly fringed at the upper part, are spirally arranged These are known as the **bract scales** or **carpellary scales** (FIG. 12) corresponding to the carpels or megasporophylls. They are inconspicuous in the mature cone. On the upper surface of each bract scale there is another stouter scale, woody in nature, known as the **ovuliferous scale** (FIG. 12), much bigger than the former. This is variously interpreted as an open carpel, a placenta or a ligular outgrowth. At the base of each ovuliferous scale, lying on its upper surface, there are two ovules with their micropyles turned downwards towards the axis of the cone. Each ovule (FIG. 13) consists of a central mass of tissue—the **nucellus** or **megasporangium**, surrounded by a *single* integument. The micropyle is rather wide. Within the nucellus a megaspore mother cell is produced which divides to form a row of four megaspores. Only one megaspore is functional; while the other three degenerate.

Male Gametophyte (FIG. 15*A*). The microspore or pollen grain begins



Pinus. FIG. 15. *A*, pollen and male gametophyte; *B*, pollen-tube; *C*, lower portion of the pollen-tube. *W*, wing; *P.C*, prothallus cells; *A.C*, antheridial cell; [illegible]; *G.C*, generative cell; [illegible]

to divide before it is set free from the microsporangium or pollen-sac and gives rise to the extremely reduced male prothallus (gametophyte) within the microspore coat. The prothallus consists of (*a*) 2 or 3 small cells (prothallus cells) which soon become disorganized, and (*b*) an antheridial cell which is the remaining large cell of the prothallus. The antheridial cell divides and forms a generative cell and a tube cell. The pollen grain sheds at this stage and subsequent changes take place after pollination.

Female Gametophyte (FIG. 13). The megaspore germinates *in situ* before fertilization and gives rise to the female prothallus within the nucellus. The female prothallus, designated as the endosperm, is completely *endosporous*; it remains permanently enclosed within the nucellus. The endosperm grows quickly after fertilization, invades the nucellus, and surrounds the embryo in the seed. Lying embedded in the prothallus there are 2-5 archegonia (FIG. 14) which are very [illegible] *Selaginella*. As in *Selaginella*, each archegonium [illegible]

[illegible]

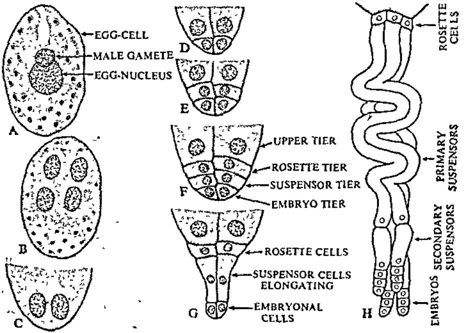
disorganized. The neck consists of 2 or more neck cells but no neck canal cell. The rest of the archegonium is filled with food. The ovules are mostly orthotropous in gymnosperms.

Pollination. Pollination takes place in the same way as in angiosperms. Pollen grains or microspores being provided with wings are easily carried by the wind to th[illegible] quantity is wasted, however. They pass bet[illegible] and are deposited at their base. A[illegible] the [illegible] na[illegible]
The mucilage is drawn in by the nucellus together with the micro-spores. The latter then lodge at the apex of the nucellus. Pollination takes place in May or June soon after the young female cone emerges from the bud. But fertilization is usually brought about in the following year at about the same time, and in the third year the cone is mature.

Fertilization (FIG. 16A). The mode of fertilization in *Pinus* was first discovered in [illegible] the male gam[illegible] covered in 18[illegible] nucleus, and the process is as follows. [illegible] coat (exine) of the pollen grain bursts and the inner coat (intine) grow[illegible] (FIG. 16C) whi[illegible] gonium. The pollen-tube [illegible] angiosperms. The tube nucleus passes into the pollen-tube. The

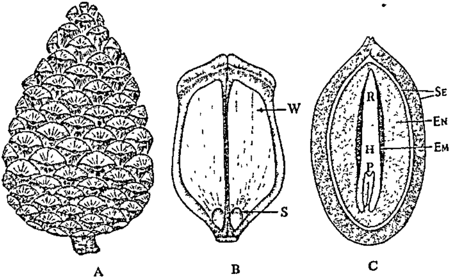
generative cell divides and forms a stalk cell and a body cell. Both these cells migrate into the pollen-tube. The stalk cell is sterile and the body cell divides and produces two male gametes. The male gametes are not ciliate, as in cycads. The pollen-tube bursts at the apex and the two male gametes are liberated. The nucleus of the functioning male gamete slips out of the cytoplasm and passes on to the egg-nucleus.[1] The other male gamete, the stalk cell and the tube nucleus become disorganized after discharge from the pollen-tube.

Development of the Embryo (early stages; FIG. 16 *B-H*). By two successive divisions of the fusion-nucleus four free nuclei are formed within the egg-cell (*B*). These then move to the bottom of it in a horizontal plane (*C*). The four nuclei divide



[1] The male and the female gametes do not fuse in the resting stage but form two separate spindles with their respective chromosomes (12 in number) within the egg-nucleus. The two sets of chromosomes then orient themselves on a common spindle and their separate identity is lost. The chromosomes (24 in number) split longitudinally and the two sets *move to the two opposite poles forming two* daughter nuclei which immediately divide into four.

again and walls appear between them (*D-E*). Further divisions result in the formation of four tiers of four cells each; this 16-celled structure is called the



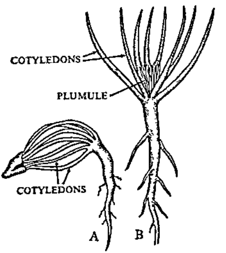
Pinus. FIG 1
phyll with 2 se
EM, embryo (
radicle); *EN*,

proembryo (*F*) Th
without cell-walls,

tive tissue. The next tier of four cells constitutes what is called the 'rosette tier'; the rosette cells may develop short and abortive embryos; normally it transmits food to the sus-

cells is the 'embryo tier'. The suspensor cells begin to elongate rapidly

perm). The embryonal cells (*G*) divide and give rise to *four* potential embryos and also secondary suspensor cells (H). This **polyembryony** (see p. 345), i e. the development of more than one embryo from an oospore, is characteristic of conifers. Of the four embryos thus formed the strongest one only survives and reaches maturity, while the others degenerate. The mature



Pinus. FIG. 18. *A-B*, germinating seed and seedling.

seed has thus only one embryo. Besides, as there are a few archegonia in the ovule some more embryos may begin to develop but finally, as stated above, only one survives.

Seed. Even before fertilization the megasporophylls show considerable growth. After fertilization, however, the ovules develop into seeds (FIG. 17*B*-*C*), and the whole female flower into a dry brown woody cone (FIG. 17*A*). The seed is albuminous in all gymnosperms, and in *Pinus* the seed-coat is provided with a membranous wing (FIG. 17*B*) which is formed from the ovuliferous scale. The seed-coat (integument) has three layers—the inner and the outer being thin and the middle stony. The fully developed embryo of the seed (FIGS. 17*C* & 18) consists of an axis with a hypocotyl, a radicle, a tiny plumule and a number of cotyledons (2-15) surrounding the plumule. Under suitable conditions the seed germinates (FIG. 18). The cotyledons are pushed upwards, germination being epigeal, and they turn green in colour, while the radicle grows downwards into a distinct tap root. The seedling thus becomes established.

Chapter 4 GNETALES

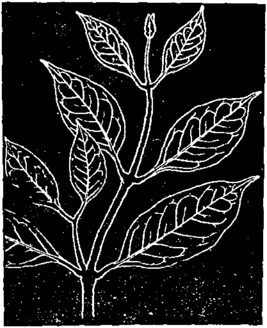
Among the gymnosperms Gnetales have reached the summit of development (evolution) and bear a close resemblance to the angiosperms. Gnetales, however, cannot be regarded as the ancestors of the angiosperms. The living Gnetales are so much advanced and so highly specialized and the fossil forms so few that their origin from any particular group of gymnosperms cannot be traced. They may have originated from an extinct group of gymnosperms—the Cordaitales, and have followed a parallel line of evolution with the angiosperms. The order Gnetales is represented by one family with three genera—*Ephedra* with 35 species, *Welwitschia* with 1 species and *Gnetum* with 35 species, altogether 71 species.

GNETUM (*35 sp.*)

Gymnospermic Characters of *Gnetum*. (1) Ovules are naked, i.e. not enclosed within the ovary. (2) In pollination the wind-borne pollen grains are lodged directly on the ovule, there being no style, stigma or ovary. (3) Male and female strobili are of gymnospermic types although the flowers are more advanced with the development of the perianth. (4) The generative cell divides and produces a stalk cell and a body cell, the latter forming two male gametes. (5) Anatomically there is preponderance of gymnospermic tracheids with bordered pits. (5) Vascular bundles are in successive concentric rings, as in some cycads.

Resemblances with Angiosperms. *Gnetum* resembles angiosperms in many features —vegetative, anatomical and reproductive. (1) *Gnetum* bears well-developed broad evergreen leaves with distinct reticulate venation, hardly distinguishable from those of angiosperms (FIG. 19). (2) The general climbing habit of *Gnetum* is more angiospermic than gymnospermic. (3) There are true vessels (of angiospermic type) present in the secondary wood in addition to the tracheids (of gymnospermic type). (4) There is a perianth present in both the male and the female flowers. (5) There are two integuments surrounding the ovule. (6) Archegonia are altogether wanting, as in the angiosperms. (7) The female gametophyte with many free nuclei has a close resemblance to the embryo-sac of an angiosperm. (8) The stamen (microsporophyll) with a stalk (filament) and 1 or 2 anthers resembles that of an angiosperm. (9) The male gametophyte produces no prothallus cells, as in all angiosperms (10) The endosperm is formed after fertilization.

Life-history. *Gnetum* ...
species in India, i.e. ...
spread in Assam. Th... (e.g. *G. montanum*) or shrubs or small trees (e.g. *G. gnemon*). Leaves are simple, decussate, broad, evergreen, leathery, lanceolate-ovate and distinctly net-veined (suggestive of dicotyledons). The primary stem often produces two kinds of shoots—the long and the short, the latter bearing one to a few pairs of leaves. Anatomically the primary vascular bundles are formed in a ring, and the secondary vascular bundles are formed in successive concentric rings by successive cortical cambia, the primary cambium being short-lived. The secondary xylem is made of true vessels (as in angiosperms) associated with gymnospermic tracheids with bordered pits. The peculiarity with the phloem is that the sieve-tube and the companion cell are formed from two separate cells (and not by the division of a single cell, as in angiosperms). Resin-ducts are absent unlike other gymnosperms.



Gnetum. FIG 19. A branch with leaves (reticulate venation).

Species of *Gnetum* are dioecious, one plant bearing male inflorescences (strobili) and another female strobili. The strobili are commonly branched, pendulous and catkin-like, bearing numerous male or female flowers, as the case may be. The strobili are commonly axillary, sometimes terminal, and grow to a length of two to a few cm.

Male Strobilus. The male strobilus (FIG. 20 A-B) is a slender axis growing between two bracts at the base, and then at short intervals pairs of bracts, fused at an early stage into a cup-shaped structure, appear. In the axils of this cup numerous minute male flowers develop in 2-5 whorls round the axis. There may be a whorl of sterile

Gnetum.
FIG. 20.
A, a male strobilus;
B, a portion of the male strobilus (magnified) showing whorls of male flowers (*FL*) in the axils of cup-shaped bracts (*BR*) on an elongated axis (*A*);
C, a male flower; *AN*, anther; *F*, filament; *P*, perianth; *H*, jointed hairs;
D, microspore (pollen grain) and stages in the development of the male gametophyte (*I-V*); *T*, tube nucleus; *G*, generative nucleus; *S*, stalk nucleus; *B*, body nucleus; *M*, male gametes.

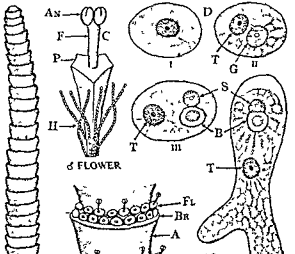
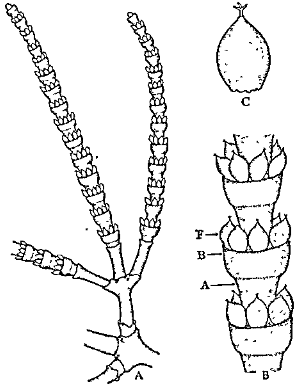


Fig. 20D redrawn after Fig. 392 in Gymnosperms: Structure and Evolution *by C. J. Chamberlain by permission of The University of Chicago Press. Copyright 1935.*

female flowers (ovules) interposed between the whorls of male flowers. Each male flower (FIG. 20C) consists of a sheathing perianth (two segments fused into a tube), often surrounded at the base by jointed hairs, and a single stamen or microsporophyll. The latter consists of a stalk (filament) and two unilocular anthers containing pollen grains or microspores. Each anther opens by a terminal slit. The presence of the perianth is an angiospermic character.

Female Strobilus (FIG. 21 A-B). This is also a slender axis, branched or unbranched, growing between two bracts at the base. The female flowers, each represented by a single ovule, are arranged in successive whorls round the axis in the axils of connate cup-shaped bracts (two

bracts fused early into a cup). There are 4-10 female flowers or ovules in each whorl. Each ovule (FIG. 21C) is surrounded by a fleshy perianth (two outgrowths appearing from the base of the ovule get fused at a very early stage) forming the outer covering. The perianth finally turns orange red in colour in the seed. The ovule (FIG. 22*A*) consists of two envelopes or integuments and a distinct nucellus or megasporangium, and is orthotropous in nature. Of the two integuments the outer one is stony and the inner one is projected beyond



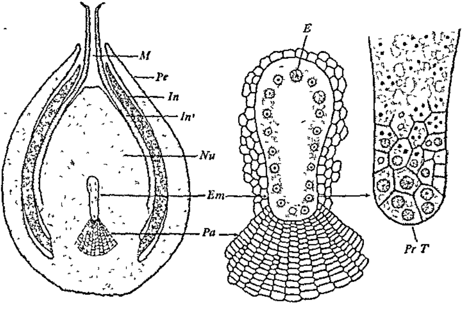
Gnetum. FIG. 21. A, a female strobilus; B, a portion of the same (magnified) showing whorls of female flowers (*F*) in the axils of cup-shaped bracts (*B*) on an elongated axis (*A*); C, a female flower (ovule) magnified.

the perianth into a sort of style or micropylar tube with its tip lobed or fimbriated. The embryo-sac or megaspore lies embedded in the nucellus towards the chalazal end. Beneath this a fan-shaped nutritive tissue, called the *pavement tissue*, formed of radiating rows of cells, develops in the nucellus. It, however, becomes disorganized after fertilization.

Male Gametophyte (FIG. 20D). Pollen grains often germinate while still in the micropylar chamber. Some of them, however, directly reach the nucellus and germinate there. The pollen grain on germination gives rise to a very simple type of male gametophyte without any prothallus cell, as in angiosperms. The nucleus of the pollen grain or microspore (1) divides at first into two nuclei, one of which is the vegetative or tube nucleus and the other the antheridial or

generative nucleus (II). The latter divides further into a stalk nucleus and a body nucleus (III). The body nucleus organizes itself into a cell with a cell-wall. The exine of the pollen grain falls off and the intine grows into the pollen-tube (IV). The body cell and the tube nucleus (but not the stalk nucleus) move forward into the pollen-tube. The body cell again divides and produces two male gametes which migrate to the tip of the pollen-tube (V).

Female Gametophyte (FIG. 22*B*). The megaspore mother cell divides and produces four megaspores, one or more of which may be functional. The megaspore germinates with repeated free nuclear divisions



A B C

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and gives rise to the embryo-sac or female gametophyte which lies deep-seated in the nucellus. One or more of the free nuclei, particularly at the *micropylar end, may be organized with a mass of* protoplasm around them into potential egg-nuclei, and may be fertilized. No archegonium is formed in *Gnetum* (cf. angiosperms). In some species, as in *G. gnemon*, a multinucleate (later uninucleate) cellular tissue (prothallial tissue), interpreted as homologous with the antipodal cells of angiosperms, is formed at the basal part of the female gametophyte (FIG. 22*C*); after fertilization it fills up the whole

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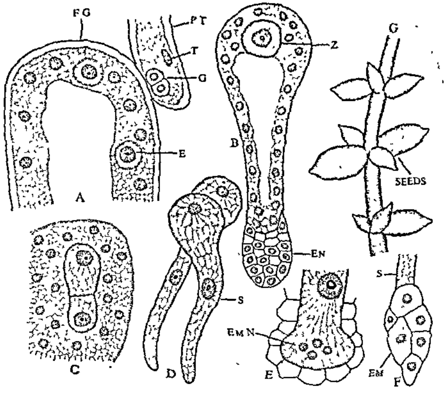
of the gametophyte. In gymnosperms the prothallial tissue is designated as the endosperm. It is noticeable that the female gametophyte of *Gnetum* with many free nuclei and without any trace of archegonium has almost reached the angiosperm level.

Fertilization and Development of the Embryo. One or more pollen-tubes penetrate through the micropylar chamber and the nucellus. Finally the tubes reach the female gametophyte (FIG. 23*A*) and enter into it. The male gametes are discharged through a terminal pore in the pollen-tube. Both the male gametes are functional, and fertilization takes place by the fusion of any of them with any free egg-nucleus. Each fertilized egg-nucleus clothes itself with a wall and becomes the oospore (FIG. 23*B*). Some of the unfertilized nuclei divide and form a prothallial tissue (endosperm), while others become disorganized. The endosperm grows quickly and soon invades



the whole of the nucellus space. In *Gnetum* most of the endosperm tissue is formed after fertilization. Many oospores or even embryos may be formed but ultimately one embryo comes to maturity. In the formation of the embryo the oospore divides and forms at first a two-celled **proembryo** (FIG. 23*C*). Each cell of the proembryo grows into a long slender tubular **suspensor** (FIG. 23*D*). Its nucleus divides into two; one of these two undergoes free nuclear divisions forming four free nuclei at the end of the suspensor (FIG. 23*E*), while the other nucleus does not divide. These four free nuclei organize themselves and give rise to the embryo (FIG. 23*F*). Further details of embryo development in *Gnetum* are not, however, known. Although there are many ovules, not many seeds are formed. The seed (FIG. 23*G*) is albuminous, the perianth fleshy and orange-red in colour, and the embryo is with two cotyledons (dicotyledonous type).

and archegonia, double fertilization, complexity of the sporophyte and extreme reduction and loss of independence of the gametophyte are some such features.

Starting from the stage of a plant with roots, stem, leaves and flowers we may follow the successive stages in its life-cycle. The flower bears a stamen or microsporophyll and carpel or megasporophyll. The stamen bears a pollen-sac or microsporangium and the carpel bears a nucellus or megasporangium within the ovule which again develops within the ovary. The pollen-sac and the nucellus in their turn produce the pollen (or microspore) mother cell and the embryo-sac (or megaspore) mother cell. By reduction division the pollen mother cell gives rise to the pollen grains or microspores, and the embryo-sac mother cell to the megaspore (of the four megaspores formed three degenerate). The pollen grain germinates on the stigma of the carpel (pistil) and gives rise to the male gametophyte (the germinating pollen grain and the pollen-tube with the three nuclei)

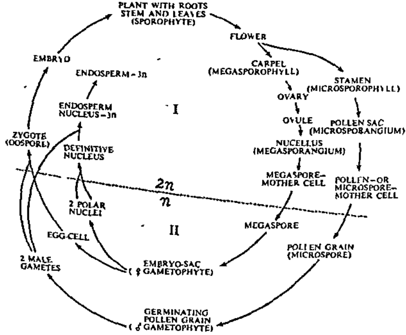


FIG. 1. Life-history of an angiosperm. *I*, sporophytic or diploid ($2n$) generation; *II*, gametophytic or haploid (n) generation.

and the megaspore to the female gametophyte (the embryo-sac with the eight nuclei). Both the gametophytes are extremely reduced and are entirely dependent on the mother sporophyte. Antheridia and archegonia are altogether absent in the gametophytes. The male gametophyte bears two male gametes and the female gametophyte bears a female gamete or egg-cell Pollination mainly takes place through the agency of insects, wind etc , and this is followed by fertiliza-
ube fuses with the egg-cell of the
vith the two polar nuclei or their
$2n$ chromosomes. As a result of
this *double fertilization* rapid changes take place in the ovule and the ovary. The fertilized egg-cell becomes the zygote (oospore) which quickly grows into the

embryo, the *triple-fusion* nucleus (two polar nuclei and one male gamete) into the endosperm (with $3n$ chromosomes), the ovule and the ovary into the seed and the fruit respectively. On germination of the seed the embryo grows and produces a new plant again with roots, stem, leaves and flowers. Thus the life-history of one generation of the plant comes to an end, and that of the next generation continues.

Alternation of Generations. In angiosperms the sporophyte has reached a high degree of complexity, while the gametophytes have become very small, simple and inconspicuous. The angiospermic plant is the sporophyte with $2n$ or *diploid* chromosomes. The embryo-sac with the eight nuclei and the germinating pollen grain including the pollen-tube with the three nuclei are the female and the male gametophytes respectively with n or *haploid* chromosomes. The endosperm with $3n$ chromosomes formed as a result of triple fusion is a unique structure in the angiosperm. All the stages from the zygote to the spore mother cells (mega- and micro-) represent the sporophytic generation, and all the stages from the spores (mega- and micro-) to the gametes (male and female) represent the gametophytic generation. These two generations (sporophytic and gametophytic) regularly alternate with each other to complete the life-cycle of an angiosperm.

Chapter 2 PRINCIPLES & SYSTEMS OF CLASSIFICATION

[illegible] in their morphological characteristics. So far as angiosperms or higher 'flowering' plants are concerned it has been estimated that over 199,000 species (dicotyledons—159,000 and monocotyledons—40,000) are already known to us, and that many thousands more have yet to be discovered and recorded. Thus plants are not only numerous but are of varied types, and it is not possible to study them unless they are arranged in some orderly system. The object of systematic botany or taxonomy is to describe, name and classify plants in such a manner that their relationship with regard to their descent from a common ancestry may be easily brought out. The ultimate object of classification is to arrange plants in such a way as to give us an idea about their phylogenetic relationships, *i.e.* the sequence of their origin and evolution from simpler, earlier and more primitive types to more complex, more recent and more advanced types in different periods of the earth. The earlier classifications of plants were based on their economic uses, e.g. cereals,

medicinal plants, fibre-yielding plants, oil-yielding plants, etc., or on gross structural resemblances, e.g. herbs, shrubs, trees, climbers, etc. These classifications were incomplete and fragmentary as plants that did not fit into such classifications or were of no economic value were usually ignored. An ideal system of classification should, therefore, not only indicate the actual genetic relationship but should also be within a reasonable limit of convenience for practical purposes.

Units of Classification

Species. By the term species we mean a collection of individuals (plants) which resemble one another in almost all important morphological characters—both vegetative and reproductive—so closely that they may be regarded as having been derived from the same parents. Take pea, for instance. The individuals in a field may differ from one another in the size of the plant or the shape of the fruit or in some minor characters, but they show a remarkable resemblance among themselves as regards the general appearance, and the structure of leaves, flowers, fruits and seeds. The resemblance among the individuals is so close that all pea plants may be regarded as having been derived from the same parents. Thus all pea plants constitute a species. Similarly all banyan plants, all peepul plants, and all mango plants constitute different and distinct species.

Occasionally due to variations in climatic or edaphic conditions individuals of a species may show a certain amount of variation in form, size, colour and other minor characteristics. Such plants are said to form **varieties**. A species may consist of one or more varieties or none at all. We have thus different varieties of common garden pea, rice, mango, etc. Varieties, however, are not permanent. They tend to revert to the original species from which they were derived.

Genus. A genus is a collection of species which bear a close resemblance to one another in the morphological characters of the floral or reproductive parts. For example, banyan, peepul and fig are different species because they differ from one another in their vegetative characters such as the habit of the plant, the shape, size and surface of the leaf, etc. But these three species are allied because they resemble one another in their reproductive organs, namely, inflorescence, flower, fruit and seed. Therefore, banyan, peepul and fig come under the same genus and that is *Ficus*.

Nomenclature. A plant name has two parts. The first refers to the genus and the second to the species. This system of designating every type of plant with a *binomial*, i.e. a name consisting of two parts, is known as binomial nomenclature, and was first established by

Linnaeus and finally settled by the International Botanical Congress[1] held at Amsterdam in 1935. Thus pea has received the name of *Pisum sativum*, rice *Oryza sativa*, mango *Mangifera indica*, banyan *Ficus bengalensis*, peepul *Ficus religiosa*, fig *Ficus glomerata*, and India-rubber plant *Ficus elastica*. Referring to cottons, we find that they all belong to the same genus *Gossypium* which consists of about 12 or more species such as BANI cotton of India (*Gossypium indicum*), KUMPTA cotton of the southern Maratha country (*G. herbaceum*), American cotton (*G. barbadense*), KIL cotton of Assam (*G. cernuum*), BURI cotton—the upland American cotton naturalized in India (*G. hirsutum*) and so on. The name of the author who first described a species is also written in an abbreviated form after the name of the species, e.g. *Mangifera indica* Linn. Here Linn. refers to the author 'Linne' or 'Linnaeus' who first described the plant.

Family. A family is a group of genera which show general structural resemblances to one another mainly in their floral organs. Thus in the genera *Gossypium*, *H* [illegible] we find free lateral stipules, [illegible] monadelphous stamens, unil [illegible] So all the above-mentioned [illegible] that is *Malvaceae*.

Systems of Classification

Systems of classification may be artificial, natural or phylogenetic. Systems have developed in a stepwise manner from the earliest to the present times, and four periods depending on criteria used in classification may be recognized. *1st period*: this extends over several centuries from about 300 B.C. to the end of the 17th century; during this period systems were based on the habit of plants. *2nd period*: this extends from the thirties to the end of the 18th century; this period records a definite change in the pattern of systems; the habit has given place to sex organs (stamens and carpels) of plants, and Linnaeus' sexual system of classification (1735) is specially remarkable. *3rd period*: this extends from the beginning to the eighties of the 19th century; there are several famous botanists of this period; systems propounded during this period have been based on natural relationships of forms; Bentham and Hooker's natural system of classification (1862-83) is of outstanding merit. *4th period*: this period extends from 1875 (possibly 1883) to the present times;

[1] International Rules of Botanical Nomenclature formulated by the International Botanical Congress at Vienna 1905, Brussels 1910, Cambridge 1930, Amsterdam 1935, and further revised by the American Society of Plant Taxonomists, 1946-7, Stockholm 1950, and Paris 1954 to synchronize with the centenary of the Botanical Society of France (1854-1954).

systems of this period have been based on phylogenetic relationships of plants.

Artificial System. In the artificial system only one or at most a few characters are selected arbitrarily and plants are arranged into groups according to such characters; as a result closely related plants are often placed in different groups, while unrelated plants are often placed in the same group because of the presence or absence of a particular character. This system enables us to determine readily the names of plants but does not indicate the natural relationship that exists among the individuals forming a group. It may thus be compared to the manner of arrangement of words in a dictionary in which [illegible] system is of very great advantage in view of the fact that by following this system of classification one can without much difficulty get to the name of an unknown plant, or in other words, the identification of an unknown plant is rendered much easier by this system.

Linnaean System (1735). The best-known artificial system is that promulgated by Linnaeus (1707-78) and published by him in the year 1735, further revised in his *Genera Plantarum* (1737) and *Species Plantarum* (1753). By 1760 his system became popular in Holland and Germany and partly in England. Linnaeus classified plants according to the characters of reproductive organs, viz. stamens and carpels. Since these are regarded as the sexual organs of plants, this artificial system of Linnaeus is commonly called the 'Sexual System'. According to this system plants are mainly divided into 24 classes including 23 of phanerogams and one of cryptogams. Phanerogams were further sub-divided into groups with unisexual or bisexual flowers. Plants with unisexual flowers were again divided according to whether they were monoecious or dioecious. Further classification was based on the number of stamens. Plants with bisexual flowers were classified according to whether the stamens were united with the carpels, or were free from them. The next consideration was whether the stamens were free or united. Then the number of stamens, their length, and ultimately the number of carpels were taken into account.

Natural System. In [illegible] are taken into consi[illegible] their related charac[illegible] differences, mostly in their important morphological characters, plants are first classified into a few big groups. These are further

CLASS II. MONOCOTYLEDONES

[illegible] with [illegible] orders [illegible] tly at least; ovary often inferior; seeds with copious endosperm) with 7 orders—*Scitamineae*, *Amaryllideae*, etc. Series (*iii*) Coronarieae (perianth partly petaloid; ovary superior; seeds with copious endosperm) with 8 orders—*Liliaceae*, *Commelinaceae*, etc. Series (*iv*) Calycinae (perianth sepaloid; ovary superior; endosperm copious) with 3 orders—*Palmaceae*, etc. Series (*v*) Nudiflorae (perianth absent or represented by scales; ovary superior; carpels 1-∞, syncarpous; endosperm usually present) with 5 orders—*Aroideae*, *Lemnaceae*, etc. Series (*vi*) Apocarpae (perianth in 1 or 2 whorls or absent; ovary superior, apocarpous; endosperm absent) with 3 orders—*Alismaceae*, etc. Series (*vii*) Glumaceae (flowers solitary, sessile, in the axils of bracts or glumes, in spikelets; perianth absent or modified into scales; ovary 1-locular, 1-ovuled; endosperm copious) with 5 orders—*Cyperaceae*, *Gramineae*, etc.

Merits. (1) Bentham and Hooker's system is a masterpiece of work on systematic botany. Some even go so far as to say that this system should have been further elaborated rather than replaced (2) The placing of Ranales at the beginning of the system is very reasonable. This is also Hutchinson's view. Engler, however, holds a different view. (3) It is a natural system, and for its practical utility it is widely followed. (4) Monocotyledons are placed after dicotyledons, but the interpolation of gymnosperms in between them is an anomaly. (5) Position of many cohorts (orders), though not the series, of Monochlamydeae is natural, e g Cactales is regarded by them as well as by Hutchinson as related to Passiflorales, while Engler places the group near Myrtiflorae. (6) The system ends in *Verbenaceae* and *Labiatae* (leaving out Monochlamydeae). This view is shared by Hutchinson also, but not by Engler.

Demerits. (1) The greatest drawback of the system is the unfortunate introduc-

[illegible]

orders have become separated, often widely. (3) Microspermae (*Burmanniaceae*

[illegible]

however, split it up into a number of smaller orders [illegible] *Liliaceae* and is placed together with *Bromeliaceae*, *Irideae* and *Amaryllideae*; while Engler raises it to the rank of an order with four families and places it

after *Liliaceae* from which it may have been derived. Hutchinson calls the order Zingiberales and includes a number of small families in it, and places it back to its former position.

Phylogenetic System. This is based on phylogenetic relationship of plants bearing on the concepts of evolution. The systems of classification proposed by Engler, a German botanist, in 1886, by Hutchinson, an English botanist, in 1926, and by Tippo, an American botanist, in 1942 are phylogenetic.

Engler's System. Engler's system is based on Eichler's system (1883), the major categories of that system having been accepted by Engler and his associates. Adolf Engler (1844-1930), Professor of Botany at the University of Berlin, first proposed his system in 1886 as a guide to the botanical garden at Breslau. The system was published in an expanded and elaborated form in *Die Naturlichen Pflanzenfamilien* (1887-1909) in 23 volumes covering the whole range of the plant kingdom, under the editorship of Engler and Prantl. Engler and Gilg's *Syllabus der Pflanzenfamilien* published in 1892 gives a comprehensive idea about the systematic classification of 'flowering' plants and cryptogams, and is a very useful publication. According to Engler's system the plant kingdom has been divided into 13 divisions, of which the seed-bearing plants (Spermatophyta) form the last division named 'Embryophyta Siphonogama'. This has been further divided into two sub-divisions—(1) Gymnospermae and (2) Angiospermae; the latter further divided into two classes—(*a*) Monocotyledoneae and (*b*) Dicotyledoneae. The former has been directly divided into 11 orders with 45 families, while the latter into two sub-classes—(*i*) **Archichlamydeae** containing 30 orders with 190 families representing the lower dicotyledons, and (*ii*) **Sympetaleae** (or Metachlamydeae) containing 10 orders with 53 families representing the higher dicotyledons. The orders have been further sub-divided into sub-orders, families and genera. There are altogether 288 families. Monocotyledoneae begins with *Typhaceae* and ends in Orchidaceae, while Dicotyledoneae begins with *Casuarinaceae* and ends in *Compositae*.

The principle involved in this system of classification is tracing the increasing complexity of flowers, particularly their accessory whorls, viz. achlamydeous flowers (no perianth), haplochlamydeous flowers (one whorl of perianth) and diplochlamydeous flowers (two whorls of perianth). Those with no perianth or with only one whorl or with polypetalous corolla form the sub-class **Archichlamydeae**; gamopetalous condition with 1 or 2 whorls of perianth comes under the sub-class Sympetaleae. The latter represents more advanced groups of dicotyledons. Within the sub-class progress is indicated through hypogyny, perigyny and epigyny, and from a variable number of stamens and carpels to a definite number. Among dicotyledons Engler starts with the family *Casuarinaceae* on the assumption that

woody plants with unisexual apetalous flowers borne in catkins are the most primitive.

Merits. (1) Classification of the whole plant kingdom with necessary sketches, records of numbers of species, and keys for identification of all known genera of plants (2) A natural system based on relationship and compatible with evo-

a new group, i.e. sub-class Archichlamydeae. (6) *Compositae* and *Orchidaceae* are considered, very reasonably, the highest families of dicotyledons and monocotyledons respectively in view of their most highly evolved characters. Because of its merits Engler's system was accepted by American and British botanists.

them. Th

accepted

ceae, etc.,

sperms with unisexual strobili. (4) The system as a whole cannot be regarded as phylogenetic. (5) Position of Helobiae, e.g. *Potamogetonaceae*, *Alismaceae*, *Hydrocharitaceae*, etc., between Pandanales and Glumiflorae is very unsatisfactory; both Pandanales and Glumiflorae are advanced groups. (6) Similarly, *Araceae*, *Lemnaceae* and *Typhaceae* are supposed to be derived from *Liliaceae*, and, therefore, cannot precede it.

Hutchinson's System. John Hutchinson, formerly Director of Royal Botanic Gardens at Kew, England, is a leading exponent of a phylogenetic system of classification. He classified only the angiosperms in his famous work *The Families of Flowering Plants*, vol. I (dicotyledons) which appeared in 1926, and vol. II (monocotyledons) in 1934. The system has been revised in his *British Flowering Plants* published in 1948, and in the second edition of *The Families of Flowering Plants* published in 1959. His system differs from all other previous ones in several fundamental facts. It is, however, nearer to Bentham and Hooker's or Bessey's in some respects rather than to Engler's. The main features of his system are as follows.

The system is based on the logical interpretation of the theory that the parts of an angiospermic flower are modified leaves. He traced the origin of angiosperms from the hypothetical pro-angiosperms of Arber and Parkin and considered it monophyletic. He emphasized the old view of arborescent and herbaceous types of primitive dicotyledons, of course, together with other connected characters. Accordingly he recognized two sub-phyla in them—Lignosae, fundamentally and predominantly woody and giving rise to orders that

are mostly woody, e.g. Magnoliales, and Herbaceae fundamentally and predominantly herbaceous and giving rise to mostly herbaceous orders, e.g. Ranales; these two sub-phyla are believed to have developed in nature on two parallel lines. Groups having both herbaceous and woody forms are considered polyphyletic. i e. members originating from different ancestors, e.g. Apetalae, Urticales, Umbelliflorae, etc. He further assumed that monocotyledons have been derived from dicotyledons at a very early stage, the point of origin being the Ranales, and that dicotyledons have been derived from gymnosperms with bisexual strobili. Primitive and advanced characters considered ... tion is ... s have ... rather ... free parts on the whole are thought more primitive than connate or adnate parts; numerous free stamens are earlier than few or connate stamens; bisexual flowers precede unisexual ones; spiral arrangement of parts is more primitive than cyclic.

Hutchinson classified the 'flowering' plants into two phyla: gymnosperms and angiosperms; the latter into two sub-phyla: dicotyledons and monocotyledons. Dicotyledons have been divided into two divisions: **Archichlamydeae** (with 59 orders) and **Metachlamydeae** (with 17 orders), and monocotyledons (with 29 orders) into three divisions: Calyciferae, Corolliferae and Glumiflorae. He has placed gymnosperms first, then dicotyledons and finally monocotyledons. There are altogether 332 families of angiosperms—264 of dicotyledons and 68 of monocotyledons. Dicotyledons begin with *Magnoliaceae* and end in *Labiatae*, while monocotyledons begin with *Butomaceae* and end in *Graminaceae*.

Merits. (1) In the opinion of most taxonomists this ... Magnoliales representing arborescent families, and Ranales representing herbaceous families, giving rise to woody and herbaceous forms respectively on parallel lines. (3) Bisexual flowers precede unisexual flowers. (5) Amentiferae is regarded as a heterogeneous group; Salicales, for example (considered primitive by Engler and closely related to gymnosperms) is placed close to Rosales (possibly derived from it) and Leguminosae, considering the flowers as specialized but reduced. (5) Apetalae is considered as having been derived partly through Magnoliales and partly through Ranales. (6) Several big orders have been split up into distinct small orders, thus simplifying matters, e g. Rosales, Parietales, Malvales, etc. (7) Many families have been raised to the rank of orders, e g. *Leguminosae* (now to an order), *Saxifragaceae* to Saxifragales, *Podostemaceae* to Podostemales, etc. (8) Reshuffling of ... Butomales and Alismatales as starting points of monocotyledons.

(11) Reshuffling of genera of *Liliaceae* and *Amaryllidaceae*. (12) Rearrangemen of several orders, finally ending in Cyperales and Graminales.

Demerits. (1) Many doubt the wisdom of his rigid distinctions between arbores cent and herbaceous families of plants. (2) Many hold different views regardin the relationships between various orders and families. (3) Polyphyletic origi of Amentiferae (catkin-bearing families with unisexual flowers). (4) Monophy letic origin of monocotyledons, as against the polyphyletic (diphyletic) view of Lotsy (1911) and Hallier (1912). (5) Urticales, Umbelliflorae, etc., as orig nating from different ancestors.

Dicotyledons and Monocotyledons. The division of angiosperms int the two great classes is based on the following characters: (1) i dicotyledons the embryo bears *two cotyledons*, whereas in mono cotyledons it bears *only one*. (2) In dicotyledons the primary roo [illegible]

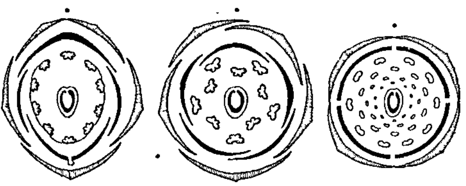
[illegible] ledons and *parallel* in monocotyledons; among monocotyledon aroids, sarsaparilla (*Smilax*) and yams (*Dioscorea*), however, shov reticulate venation, and among dicotyledons Alexandrian laure (*Calophyllum*) shows parallel venation. (4) The dicotyledonous flowe [illegible]

[illegible] dary growth, while in the monocotyledonous stem the bundles ar *scattered* in the ground tissue and are *collateral* and *closed* (with bu few exceptions), and hence there is no secondary growth; also th bundles are more numerous in monocotyledons than in dicotyledons further, the bundles are more or less oval in monocotyledons and wedge-shaped in dicotyledons. (6) In the dicotyledonous root the num- [illegible]

[illegible] secondary growth.

Floral Diagram. The number of parts of a flower, their general struc- ture, arrangement and the relation they bear to one another (*aesti- vation*), adhesion, cohesion, and position with respect to the mother axis may be represented by a diagram known as the **floral diagram**. The floral diagram is the ground plan of a flower. In the diagram the calyx lies outermost, the corolla internal to the calyx, the androe- cium in the middle, and the gynoecium in the centre. Adhesion and cohesion of members of different whorls may also be shown clearly

by connecting the respective parts with lines; as, for example, FIG. 2A shows that there are altogether ten stamens, of which nine are united into one bundle and the remaining one is free. The black dot on the top represents the position of the mother axis (not the pedicel) which bears the flower. The axis lies behind the flower and, therefore, the side of the flower nearest to the axis is called the *posterior*



A B C

Floral Diagrams (three types). FIG. 2. *A*, *Papilionaceae*; *B*, *Caesalpinieae*; *C*, *Mimoseae*.

side, and the other side away from the axis the *anterior* side. The floral characters of a species may be well represented by a floral diagram, while to represent a genus or family more than one diagram may be necessary.

Floral Formula. The different whorls of a flower, their number, cohesion and adhesion may be represented by a formula known as the **floral formula.** In the floral formula K stands for calyx, C for corolla, P for perianth, A for androecium and G for gynoecium. The figures following the letters K, C, P, A and G indicate the number of parts of those whorls. Cohesion of a whorl is shown by enclosing the figure within brackets, and the adhesion is shown by a line drawn on the top of the two whorls concerned. In the case of the gynoecium the position of the ovary is shown by a line drawn above or below G or the figure. If the ovary is superior the line should be below it, and if it is inferior the line should be on the top. Thus all the parts of a flower are represented in a general way by the floral formula; the floral characters of a family may also be represented by one or more formulae, as follows. Besides, some symbols are used to represent certain features of flowers; thus ♂ represents male, ♀ female, ⚥ hermaphrodite, ♂♀ dioecious, ♂-♀ monoecious, ♂♀⚥ polygamous, ⊕ actinomorphic, ·|· zygomorphic, ∞ indefinite number of parts, etc.

Ranunculaceae:	⊕ ⚥ $K_5C_5A_{\infty}\underline{G}_{\infty}$	*Cucurbitaceae*:	⊕ ♂ ♀ or ♂-♀
Annonaceae:	⊕ ⚥ $K_3C_{3+3}A_{\infty}\underline{G}_{\infty}$		♂ $K_{(5)}C_{(5)}A_{3 \text{ or } 5}$
Nymphaeaceae:	⊕ ⚥ $K_4C_{\infty}A_{\infty}\underline{G}_{(\infty) \text{ or } \infty}$		♀ $K_{(5)}C_{(5)}\overline{G}_{(3)}$

Cruciferae: $\oplus$ ⚥ $K_{2+2}C_4A_{2+4}\underline{G}_{(2)}$ *Solanaceae*: $\oplus$ ⚥ $K_{(5)}\overline{C_{(5)}A_5}\underline{G}_{(2)}$

Malvaceae: $\oplus$ ⚥ $K_{(5)}\overline{C_5A_{(\infty)}}\underline{G}_{(1-\infty)}$ *Labiatae*: $+$ ⚥ $K_{(5)}\overline{C_{(5)}A_4}\underline{G}_{(2)}$

Features used to describe an Angiospermic Plant

I.

shr

habit.

Root: nature of the root; any special form.

Stem: kind of stem—herbaceous or woody; cylindrical or angular; hairy or smooth; jointed or not; hollow or solid; erect, prostrate, twining or climbing; nature of modification, if any.

Leaf: arrangement—whether alternate, opposite (superposed or decussate) or whorled; stipulate or exstipulate; nature of the stipules, if present, simple or compound; nature of the compound leaf and the number of leaflets; shape and size; hairy or smooth; deciduous or persistent; venation; margin; apex; and petiole.

Inflorescence: type of inflorescence (to be explained)

Flower: sessile or stalked; complete or incomplete; unisexual or bisexual; regular, zygomorphic, or irregular, hypogynous, epigynous or perigynous; bracteate or ebracteate; nature of bracts and bracteoles, if present; shape of the flowers, its colour and size.

Calyx: polysepalous or gamosepalous; number of sepals or of lobes; superior or inferior; aestivation; shape, size and colour.

Corolla: polypetalous or gamopetalous; number of petals or of lobes; superior or inferior; aestivation; shape, size, colour and scent; corona or any special feature.

(When there is not much difference between the calyx and the corolla the term **perianth** should be used; it may be sepaloid or petaloid; polyphyllous or gamophyllous, free or epiphyllous).

Androecium: number of stamens—definite (ten or less) or indefinite (more than ten); free or united; nature of cohesion—monadelphous, diadelphous, poly-

ages, if any.

Gynoecium or Pistil: number of carpels; syncarpous or apocarpous; nature of style—long or short; stigmas—simple, lobed or branched; their number and nature—smooth or papillose; ovary—superior or inferior; number of lobes; number of chambers (loculi); nature of placentation; number and form of ovules in each loculus of the ovary.

Fruit: kind of fruit (to be explained).

Seeds: number of seeds in the fruit; shape and size; albuminous or exalbuminous; nature of endosperm, if present.

Chapter 3 SELECTED FAMILIES OF DICOTYLEDONS

SUB-CLASS I POLYPETALAE

FAMILY 1 *Ranunculaceae (1,200 sp.—157 sp. in India*[1]*)*

Habit—annual or perennial herbs or climbing shrubs, usually with an acrid juice. **Leaves** simple or compound, alternate or rarely opposite, radical and cauline, usually with sheathing base. **Inflorescence** cymose. **Flowers** mostly regular (actinomorphic), sometimes zygomorphic, as in larkspur (*Delphinium*) and monk's hood (*Aconitum*), bisexual and hypogynous, often showy; sepals and petals in whorls; stamens and carpels typically spiral on the elongated thalamus. **Calyx**—sepals usually 5, sometimes more, free, sometimes brightly coloured. **Corolla**—petals 5 or more, free, sometimes absent, often with nectaries, imbricate; perianth leaves (when calyx and corolla not distinguishable) free and petaloid. **Androecium**—stamens numerous, free, usually spiral. **Gynoecium**—carpels usually numerous, sometimes few or even 1, free (apocarpous), *usually spiral, with one or more ovules in each*; in *Nigella* carpels are united at the base. **Fruit** an etaerio of achenes or follicles, rarely a berry or capsule. **Seeds** albuminous.

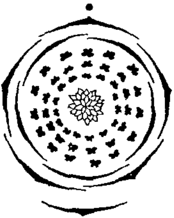


FIG. 3. Floral diagram of *Ranunculaceae*.

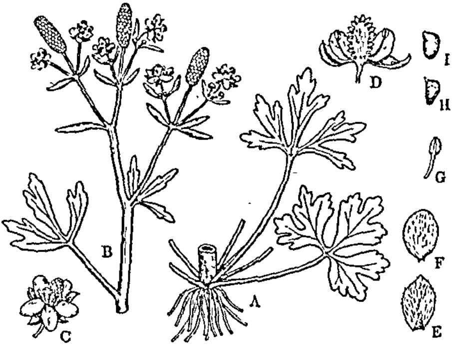
Floral formula—⊕ ⚥ $K_5C_5A_\infty\underline{G}_\infty$.

Ranunculaceae, according to Hutchinson, is a most primitive family having originated from some gymnospermous stock and showing parallel development with *Magnoliaceae* (see p. 564). The former shows evolutionary progress through herbaceous families like *Nymphaeaceae*, *Papaveraceae*, *Capparidaceae*, *Cruciferae*, etc. Hutchinson is further of the opinion that monocotyledonous families like *Alismaceae*, *Hydrocharitaceae*, etc., have evolved from Ranalean stock.

Examples. Useful plants: monk's hood or aconite (*Aconitum ferox*; B. KATBISH; H. BISH)—medicinal, tuberous roots containing a very poisonous alkaloid, black cumin (*Nigella sativa*; B. & H. KALAJIRA)—seeds used as a condiment; **ornamental:** larkspur (*Delphinium*), wind flower (*Anemone*)—a small tuberous plant with woolly achenes for wind-dispersal, virgin's bower (*Clematis*)—a climbing shrub,

[1] Figures regarding Indian species have been compiled from *Studies on the Endemic Flora of India and Burma* by D. Chatterjee.

columbine (*Aquilegia*), buttercup (*Ranunculus*), etc.; other common plants: *Ranunculus* (300 sp.—about 10 sp. in India), e.g. Indian buttercup (*Ranunculus sceleratus*) usually growing in river- and



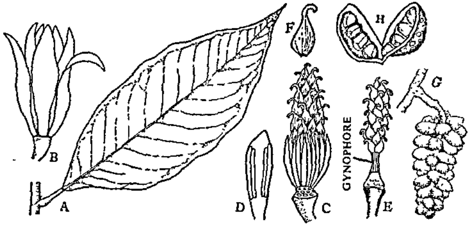
Ranunculaceae. FIG. 4. *Ranunculus sceleratus*. *A*, basal portion of the plant with leaves and roots; *B*, upper portion of the same with inflorescence; *C*, flower; *D*, flower cut longitudinally; E, a sepal; *F*, a petal; *G*, a stamen; *H*, a carpel; and *I*, a fruit (achene).

marsh-banks, water crowfoot (*R. aquatilis*) growing in water and showing heterophylly, traveller's joy (*Naravelia zeylanica*)—a climbing shrub, *Thalictrum*—a perennial herb, etc.

FAMILY 2 *Magnoliaceae (300 sp.—30 sp. in India)*

Habit—shrubs and trees. Leaves simple, alternate, often with large stipules covering young leaves. Flowers solitary, terminal or axillary, often large and showy, aromatic; they are regular, bisexual and hypogynous. **Perianth** leaves all alike, petaloid, deciduous; *either cyclic* being arranged in whorls of 3 (trimerous) or acyclic (spiral); sometimes the outer whorl sepaloid. **Androecium**—stamens numerous, free; filament short or absent; anther-lobes linear, 4, with prolonged connective. **Gynoecium**—carpels numerous, free, arranged spirally round the elongated thalamus; ovules 1 or few in each carpel. **Fruit** an aggregate of berries or follicles. Seed albuminous. Endosperm of the seed non-ruminated. *Floral formula*—$\oplus$ ⚥ $P_{\infty}A_{\infty}\underline{G}_{\infty}$.

Magnoliaceae is related to *Annonaceae* but the main distinguishing features are: the presence of big stipules in the former standing as a hood over the bud, and the presence of ruminated endosperm in the latter Hutchinson considers it as the most primitive family with a near approach to certain gymnosperms like



Magnoliaceae. FIG. 5. *Michelia champaca. A*, a leaf; *B*, a flower; *C*, stamens and carpels spirally arranged on the thalamus; *D*, a stamen with four anther-lobes; *E*, carpels (free); *F*, a carpel; *G*, aggregate fruits (follicles); and *H*, a follicle dehiscing.

Bennettitales because of spiral arrangement of free stamens and free carpels, the presence of tracheids with bordered pits, and unisexual flowers in *Drimys. Magnoliaceae* shows evolutionary progress through woody families like *Annonaceae*, *Lauraceae*, etc.

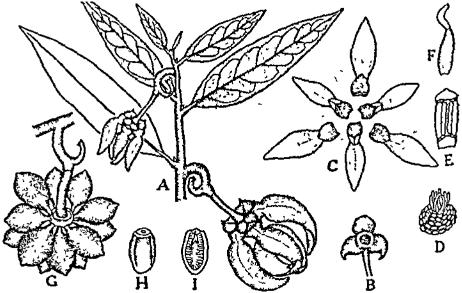
Examples. Mostly ornamental evergreen plants with fragrant flowers —*Michelia* (25 sp.), e.g. *M. champaca* (B. CHAMPA; H. CHAMPAK), *M. alba* (B. CHINA-CHAMPA), *Magnolia* (70 sp.), e.g. *M. grandiflora* (B. DULEE-CHAMPA), *M. pumila* (=*Talauma pumila*; B. JAHURE-CHAMPA) and *M. fuscata* (B. CHINI-CHAMPA).

FAMILY 3 *Annonaceae (820 sp.—100 sp. in India)*

Habit—shrubs and trees, sometimes climbers. **Leaves** simple, alternate, distichous and exstipulate. **Flowers** regular, bisexual, and hypogynous; often aromatic. **Perianth** usually in three whorls of three members each; sepals 3 and petals 6 in two whorls. **Androecium**—stamens numerous, free, arranged spirally round the slightly elongated thalamus; filament short or absent; anther-lobes linear, 4, with prolonged connective. **Gynoecium**—carpels numerous, free or connate; ovules one to many in each carpel. **Fruit** an aggregate of berries. **Seed** with the endosperm distinctly ruminated, i.e. marked by irregular wavy lines. *Floral formula*—$\oplus$ ⚥ $K_3C_{3+3}A_{\infty}\underline{G}_{\infty}$.

Annonaceae is allied to *Magnoliaceae* but is distinguished from it by the presence of deeply ruminated endosperm.

Examples. *Annona* (90 sp.), e.g. custard-apple (*Annona squamosa*), —fruit edible, bullock's heart (*A. reticulata*)—fruit edible, sour sop (*A. muricata*)—fruit edible, *Artabotrys* (30 sp.), e.g. *A. odoratissimus* —flowers fragrant, *Unona discolor* (B. LAVENDAR-CHAMPA)—flowers



Annonaceae. FIG. 6. *Artabotrys*. *A*, a branch with two flowers, *B*, calyx; *C*, petals spread out; *D*, stamens and carpels; *E*, a stamen with four anther-lobes; *F*, a carpel; *G*, an aggregate of berries; *H*, a seed; and *I*, the seed cut longitudinally showing the ruminated endosperm.

with very fragrant odour, mast tree (*Polyalthia longifolia*)—evergreen tall tree, leaves used for decoration, *Uvaria macrophylla*—a climber, and *Cananga odorata*—flowers yield Macassar oil. There is a large number of wild species of *Annonaceae*.

FAMILY 4 *Nymphaeaceae* (*100 sp.—11 sp. in India*)

Habit—aquatic perennial herbs. **Leaves** usually floating, borne on a long petiole, cordate or peltate. **Flowers** often large, showy, solitary, on a long pedicel, usually floating; bisexual, regular and usually perigynous, sometimes hypogynous or even epigynous; thalamus fleshy and goblet-shaped. **Perianth** leaves several, free; sepals usually 4, gradually merging into petals; petals numerous, gradually merging into stamens. **Androecium**—stamens numerous, free, usually perigynous, adnate to the fleshy thalamus that envelops the carpels. **Gynoecium**—carpels several, either free on the fleshy thalamus, as in lotus, or syncarpous lying embedded in the thalamus and surrounded

tary and exalbuminous, or many with both perisperm and endosperm; spongy aril is often present and helps the seed to float. *Floral formula*—$\oplus$ ⚥ $K_4 C_\infty A_\infty \underline{G}_{(\infty)}$ or ∞.

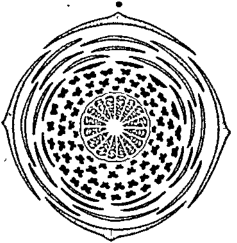
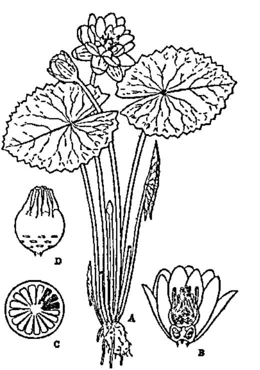


FIG. 7. Floral diagram of *Nymphaeaceae*.

Nymphaeaceae forms a link with *Ranunculaceae* and *Magnoliaceae* by spiro-cyclic nature of floral whorls, and sometimes apocarpous pistil, as in *Cabomba*. The family also bears an affinity with monocotyledons (e g. *Alismaceae*) through *Cabomba* which has a typical trimerous symmetry ($P_{3+3} A_{3-6} \underline{G}_3$), apocarpous pistil and scattered closed vascular bundles. It also shows affinity with *Papaveraceae* by its superficial placentation and radiating stigmas.

Examples. Plants often cultivated for pond decoration—water lilies (*Nymphaea* with 40 sp.), e.g. *N. lotus*, *N. rubra*, *N. stellata*, etc., *Euryale ferox* (B. & H. MAKHNA), lotus (*Nelumbium speciosum*)—rhizome eaten, and giant water lily (*Victoria regia*; see FIG. IV/1—it bears huge tray-like leaves, each measuring 1-2 metres in diameter; although a native of South America this plant may be seen in luxuriant growth about October in the Indian Botanic Gardens near Calcutta). Lotus



Nymphaeaceae. FIG. 8. Water lily (*Nymphaea lotus*). *A*, an entire plant; *B*, a flower cut longitudinally (see also FIGS. I/101-2); *C*, transverse section of the ovary; and *D*, a young fruit.

has some distinctive characteristics of its own: (1) leaves and flowers are raised above the surface of water; (2) flowers hypogynous; (3) carpels several, free (apocarpous), and embedded in the upper surface of the top-shaped thalamus; (4) ovary unilocular with one ovule; (5) stigmas sessile, solitary; and (6) seeds exalbuminous.

FAMILY 5 *Papaveraceae (700 sp.—40 sp. in India)*

Habit—mostly herbs with milky or yellowish latex. Leaves radical and cauline, simple and alternate, often lobed. Flowers solitary, often showy, regular, bisexual and hypogynous. **Calyx**—sepals typically 2, rarely 3, free, caducous. **Corolla**—petals 2+2 or many, rarely 3+3, free, rolled or crumpled in bud, caducous. **Androecium**—stamens ∞, sometimes 2 or 4, free. **Gynoecium**—carpels (2-∞), syncarpous; ovary superior, 1-chambered, or spuriously 2- to 4-chambered, with 2-∞ parietal placentae which may project inwards, as in poppy (*Papaver*); stigmas distinct or sessile and rayed over the ovary, as in poppy; ovules numerous. Fruit a septicidal capsule dehiscing by valves, or opening by pores. Seeds many, with oily endosperm. *Floral formula*—⊕ ⚥ $K_2C_{2+2}A_{\infty}\underline{G}_{(2-\infty)}$.

Examples. Opium poppy (*Papaver somniferum*)—opium is the latex obtained [illegible]

[illegible] weed bearing yellow flowers in winter, seeds yield an oil, Himalayan poppy (*Meconopsis*)—mainly occurring in Nepal and the Eastern Himalayas, and *Corydalis*—a tendril-climbing herb.

FAMILY 6 *Cruciferae (2,000 sp.—174 sp. in India)*

Habit—herbs. Leaves radical and cauline, simple, alternate, often lobed, or sometimes pinnately compound. **Inflorescence** a raceme (corymbose towards the top). **Flowers** regular and cruciform, bisexual and complete, hypogynous. **Calyx**—sepals 2+2, free, in two whorls. **Corolla**—petals 4, free, in one whorl, alternating with sepals, cruciform, each petal with distinct limb and claw. **Androecium**—stamens 6, in two whorls, 2 outer short and 4 inner long (tetradynamous). **Gynoecium**—carpels (2), syncarpous; ovary superior; at first 1-celled, but later 2-celled owing to the development of a false septum, called the *replum*; ovules often many in each cell, sometimes only 2, anatropous or campylotropous; placentation parietal. **Fruit** a long siliqua or a short silicula. Seeds exalbuminous; embryo curved. *Floral formula*—⊕ ⚥ $K_{2+2}C_4A_{2+4}\underline{G}_{(2)}$.

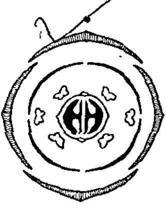
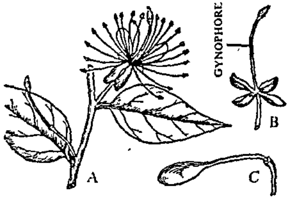


FIG. 9. Floral diagram of *Cruciferae*.

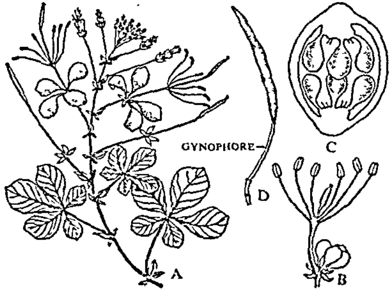
times 6 (rarely tetradynamous, as in some species of *Cleome*), free. Gynoecium—carpels typically (2), rarely many, syncarpous; gynophore often present; ovary superior, 1-celled, or chambered by false partition wall (replum), with parietal



Capparidaceae.
FIG. 11.
Capparis sepiaria.
A, a portion of a branch;
B, pistil seated on gynophore and calyx at the base;
C, a fruit.

placentation; ovules many, campylotropous. Fruit an elongated capsule or a berry. Seed exalbuminous; embryo curved in various ways.
Floral formula—$\oplus$ ⚥ $K_{2+2}C_4A_{\infty}$ or ${}_6\underline{G}_{(2)}$.

From the structure of the flower it seems *Capparidaceae* stands midway between *Papaveraceae* and *Cruciferae* (see p. 585).



Capparidaceae. FIG. 12. *Gynandropsis gynandra*. *A*, a branch with leaves and flowers; *B*, a flower; *C*, section of ovary showing parietal placentation; and *D*, a fruit.

Examples. *Polanisia icosandra* (=*Cleome viscosa*), *Gynandropsis gynandra*, *Capparis* (200 sp.), usually with spinous stipules, e g. *C. sepiaria*, *C. horrida*, *C. aphylla*—the whole leaf is modified into a tendril, caperbush (*C. spinosa*)—pickled

flower-bud of it is called caper, etc., *Crataeva religiosa* (= *C. roxburghii*) — a large tree, and *Roydsia suaveolens* — flowers delightfully scented.

FAMILY 8 *Caryophyllaceae* (2,000 sp. — 106 sp. in India)

Habit — annual or perennial herbs, with swollen nodes. Leaves simple, opposite, sessile, sometimes connate, often stipulate. Inflorescence a cyme (usually dichasial). Flowers regular, bisexual, hypogynous, caryophyllaceous. Calyx — sepals usually 5, free or slightly connate. Corolla — petals commonly 5, free, usually clawed; sometimes androphore develops. Androecium — stamens usually 10, sometimes 8, free or sometimes united at the base, in two whorls, the outer opposite the petals and the inner opposite the sepals. Gynoecium — carpels (5) or (3); ovary 1-celled due to the breaking down of the septa at an early stage; placentation central; ovules usually many; styles 5 or 3, free; stigma along the inner surface of the style. Fruit a capsule dehiscing by valves. Seeds usually many, albuminous, with curved embryo. *Floral formula* — $\oplus$ ⚥ $K_5C_5A_{5+5}\underline{G}_{(3-5)}$

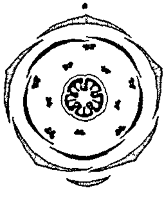


FIG. 13. Floral diagram of *Caryophyllaceae*.

Caryophyllaceae is related to *Portulacaceae*. According to Hutchinson *Amarantaceae* and *Chenopodiaceae* are derived from *Caryophyllaceae* by way of reduction of floral members, while Engler holds the reverse view.

Examples. *Dianthus* (250 sp.) — many are cultivated as ornamental flowers, e.g. pink (*D. chinensis*), carnation (*D. caryophyllus*), etc., *Drymaria cordata* — a common weed, *Saponaria vaccaria* (B. SABUNI; H. MUSNA), *Stellaria media*, *Spergula arvensis*, *Gypsophila*, *Silene* (in temperate western Himalayas), etc.

FAMILY 9 *Dipterocarpaceae* (350 sp. — 34 sp. in India)

[illegible]

the base; aestivation twisted. Androecium — stamens 5, 10, 15 or ∞, free or connate at the base; anther 2-celled, connective with an appendage. Gynoecium — carpels (3), syncarpous; ovary superior, 3-locular, with 2-∞ pendulous ovules in each. Fruit a 1-seeded nut, usually winged. Seed exalbuminous.

Floral formula — $\oplus$ ⚥ $K_5C_5A_{5,\ 10,\ 15\ \text{or}\ \infty}\underline{G}_{(3)}$.

[illegible]

robusta (B. & H. SAL, see FIG. I/170C) — a very valuable timber tree, *S. assamica* — wood somewhat softer, *Vatica lancaefolia* — used as firewood and makes good charcoal, *Vateria indica* — yields a gum-resin used for Indian copal varnish, *Hopea odorata* (see FIG. I/169C) — a tall tree, etc.

FAMILY 10 *Malvaceae*[1] (*1,000 sp.—105 sp. in India*)

Habit—herbs, shrubs and trees. **Leaves** simple, alternate and palmately-veined; stipules 2, free lateral. **Flowers** regular, polypetalous, bisexual, hypogynous, copiously mucilaginous, with a whorl of bracteoles known as the *epicalyx* (except in *Abutilon* and *Sida*). **Calyx**—sepals (5), united, valvate. **Corolla**—petals 5, free, attached to the base of the staminal tube; aestivation twisted. **Androecium** — stamens numerous, monadelphous, i.e. united into one bundle called staminal column or tube, epipetalous (staminal tube adnate to the petals at the base); anthers reniform, unilocular; pollen grains large and spiny. **Gynoecium**—carpels (1 to ∞), usually (5), syncarpous, (2-3) in *Kydia*; ovary superior, 2- to ∞-locular, with 1 to many ovules in each loculus; placentation axile; style passes through the staminal tube; stigmas free, as many

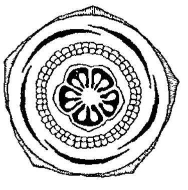
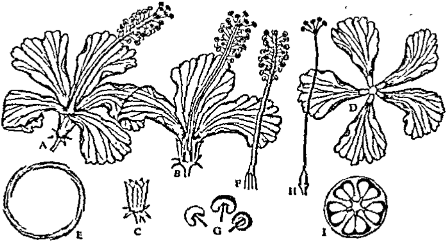


FIG. 14. Floral diagram of *Malvaceae*.



[1] Malvales of Bentham and Hooker—*Malvaceae, Tiliaceae* and *Sterculiaceae*; the same order of Engler—*Tiliaceae, Malvaceae, Bombacaceae, Sterculiaceae*, and a few more; Hutchinson has split the order into two: Malvales—*Malvaceae*, and Tiliales—*Tiliaceae, Sterculiaceae, Bombacaceae* and a few more.

as the carpels. Fruit a capsule or sometimes a schizocarp. Seed endospermic. *Floral formula*—$\oplus$ ⚥ $K_{(5)}\overline{C_5 A}_{(\infty)}\underline{G}_{(1-\infty)}$.

Malvales may be allied to Guttiferales by various degrees of union of stamens, 5-merous calyx and corolla, and hypogynous flowers, and may have a common origin.

Examples. Useful plants: *Gossypium* (12 sp.) yields commercial cotton, *Hibiscus* (200 sp.), e.g. rozelle (*Hibiscus sabdariffa*) and Madras or Deccan hemp (*H. cannabinus*) are sources of strong fibres, lady's finger (*Hibiscus esculentus*)—green fruits used as a vegetable etc., and mallow (*Malva*)—green leaves used as a vegetable; ornamental: several species of *Hibiscus*, e.g. shoe-flower or China rose (*H. rosa-sinensis*), *H. mutabilis* (B. STHALPADMA; H. GULIAJAIB), etc., Chinese lantern (*Achania malvaviscus*; B. LANKA-JABA), and hollyhock (*Althaea*); shade tree: Portia tree (*Thespesia*); other common plants: *Sida cordifolia*, *Urena lobata*, *Hibiscus vitifolius* (B. & H. BAN-KAPAS), Indian mallow (*Abutilon indicum*), *Malachra capitata* (B. & H. BAN-BHINDI), *Malvastrum*—a weed of waste places

FAMILY 11 *Sterculiaceae (700 sp.—75 sp. in India)*

Habit—shrubs or trees, rarely herbs. Leaves—leaves and stipules are like those of *Malvaceae*. Inflorescence cymose, often complex. Flowers (see FIG. I/92C) regular, sometimes zygomorphic, bisexual, rarely unisexual (as in *Sterculia*), hypogynous. Calyx and corolla as in *Malvaceae*, sometimes corolla absent; no epicalyx. Androecium—stamens usually ∞ (but varying from 5-25), typically in two whorls, the outer whorl opposite to sepals and often reduced to staminodes or absent, while the inner whorl opposite to petals, fertile and often branched; all stamens more or less united below into a tube; sometimes on gonophore; anthers 2-locular. Gynoecium—carpels (5-1), often (5), syncarpous; ovary superior, 5- to 1-locular, with 2-∞ anatropous ovules in each; style simple; stigma lobed. Fruit varying, dry or fleshy, often a schizocarp. Seed with fleshy endosperm, sometimes arillate. *Floral formula*—$\oplus$ ⚥ $K_{(5)}C_5A_{(\infty)}\underline{G}_{(5-1)}$.

[illegible] JANGLI-
[illegible] *ium* (see FIG. I/92C)—planted as a roadside tree, *Heritiera minor* (B. SUNDRI)—a common tree of the Sundarbans, wood valuable as timber and firewood, cocoa tree (*Theobroma cacao*)—cocoa and chocolate prepared from roasted seeds, devil's cotton (*Abroma augusta*; B. & H. ULATKAMBAL)—a shrub with fruits standing erect on the branches, noon flower (*Pentapetes phoenicea*)—a tall herb with red flowers, *Kleinhovia hospita* (B. BOLA)—planted as a roadside tree, *Melochia corchorifolia*—a common weed, etc.

FAMILY 12 *Tiliaceae (400 sp.—72 sp. in India)*

Habit—generally trees or shrubs, sometimes herbs. **Leaves**—leaves and stipules as in *Malvaceae*. **Inflorescence** cymose, often complex. **Flowers** regular, usually bisexual, hypogynous, pentamerous. **Calyx**—sepals (5) or 5, aestivation valvate; no epicalyx. **Corolla**—petals 5, polypetalous, rarely absent, imbricate in bud. **Androecium**—stamens usually many, free or polyadelphous, inserted at the base of the petals or on gonophore, as in *Grewia*; anther 2-locular. **Gynoecium**—carpels (2-∞), syncarpous; ovary superior, 2- to ∞-locular, with 1-∞ anatropous ovules in each; style simple; stigma capitate or lobed. **Fruit** varying, commonly a capsule, drupe or berry. **Seed** with fleshy endosperm. *Floral formula*—⊕ ⚥ $K_{(5)\ or\ 5}C_5A_{\infty}\underline{G}_{(2-\infty)}$.

Examples. Jute (*Corchorus capsularis* and *C. olitorius*), *C. acutangulus* (B. TITAPAT)—a common weed, *Grewia* (150 sp.), e.g. *G. asiatica* (B. PHALSA)—a tree bearing edible fruits, *G. multiflora*—often grown as a hedge plant, etc., *Triumfetta rhomboidea*—an undershrub with hooked fruits, *Tilia europaea*—in temperate Himalayas, etc.

Distinguishing Characters

Malvaceae	*Sterculiaceae*	*Tiliaceae*
Herbs, shrubs or trees	trees or shrubs, a few herbs	trees or shrubs, a few herbs
Leaves simple, often palmately lobed	simple or palmately compound	simple, entire or dentate
Flowers regular, bisexual, with epicalyx	regular, sometimes zygomorphic, bisexual, rarely unisexual, sometimes corolla absent, with no epicalyx	regular, bisexual, rarely unisexual, with no epicalyx
Stamens (∞), monadelphous, epipetalous; anther 1-locular	often many, typically in 2 whorls, the outer staminodes or absent, the inner fertile and branched, sometimes on gonophore; anther 2-locular	usually many, sometimes 10, free or connate at the base only, developing at the base of the petals or on gonophore, anther 2-locular
Carpels (1-∞), usually (5), with 1-∞ anatropous ovules in each chamber	(5-1), usually (5), with 2-∞ anatropous ovules in each chamber	(2-∞), with 1-∞ anatropous ovules in each chamber
Fruit capsular or schizocarpic; seed with scanty endosperm	capsular or schizocarpic; seed with fleshy endosperm	capsular or berry-like; seed with fleshy endosperm
Embryo with folded cotyledons	with flat or folded cotyledons	with large leafy cotyledons

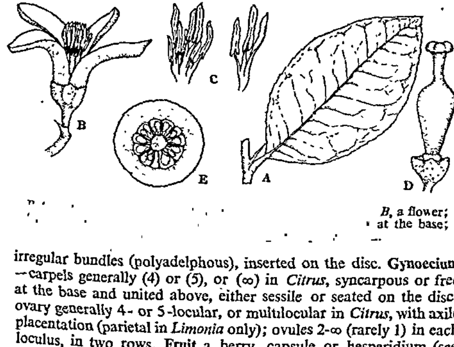
FAMILY 13 *Bombacaceae (140 sp.)*

Habit—large trees. **Leaves** simple or digitately compound, with deciduous stipules. **Flowers** regular, large, bisexual, hypogynous. **Calyx**—sepals (5), gamosepalous, valvate, often with epicalyx. **Corolla**—petals 5, polypetalous, imbricate. **Androecium**—stamens 5-∞, free or polyadelphous; anthers 2- or sometimes more-celled; pollen grains smooth; staminodes often present. **Gynoecium**—carpels (2-5), syncarpous, when 5 they are opposite to the petals; ovary superior, multilocular, with 2-∞ ovules in each loculus. **Fruit** a capsule. **Seeds** smooth, often very hairy, with scanty or no endosperm.
Floral Formula—$\oplus$ ⚥ $K_{(5)}C_5A_{5-\infty}\underline{G}_{(2-5)}$

Examples. Silk cotton tree (*Bombax malabaricum*) and white cotton tree (*Eriodendron anfractuosum*)—cotton used for stuffing pillows and cushions and wood used for making tea- and match-boxes and match-sticks, baobab tree (*Adansonia digitata*)—trunk often reaching a diameter of 9 metres, balsa (*Ochroma*)—a South American plant with very light wood, used for making models of boats, ships, etc.

FAMILY 14 *Rutaceae (1,200 sp.—66 sp. in India)*

Habit—shrubs and trees (rarely herbs). **Leaves** simple or compound, alternate or rarely opposite, *gland-dotted*. **Flowers** regular, bisexual and hypogynous; disc below the ovary prominent—ring- or cup-like. **Calyx**—sepals 4 or 5, free or connate below, imbricate. **Corolla**—petals 4 or 5, free, imbricate. **Androecium**—stamens variable in number, as many or more generally twice as many as petals (obdiplostemonous) or numerous in *Citrus* and *Aegle*, free or united in



B, a flower;
at the base;

irregular bundles (polyadelphous), inserted on the disc. **Gynoecium**—carpels generally (4) or (5), or (∞) in *Citrus*, syncarpous or free at the base and united above, either sessile or seated on the disc; ovary generally 4- or 5-locular, or multilocular in *Citrus*, with axile placentation (parietal in *Limonia* only); ovules 2-∞ (rarely 1) in each loculus, in two rows. **Fruit** a berry, capsule or hesperidium (see

p. 121). Seeds with or without endosperm. Polyembryony is frequent in *Citrus*, e.g. lemon and orange (but not pummelo and citron). *Floral formula*—$\oplus$ ⚥ $K_{4-5}C_{4-5}A_{8,10 \text{ or } \infty}\underline{G}_{(4,5 \text{ or } \infty)}$

Rutaceae is allied to *Meliaceae* by obdiplostemonous stamens (i e. stamens in 2 whorls, the outer opposite to the petals), presence of disc, carpels often (5), anatropous ovule with ventral raphe, and types of fruits. Hutchinson has separated the above two families from Geraniales and placed them under two *separate orders Rutales and Meliales respectively. Rutales is also related to* Sapindales (*Sapindaceae, Anacardiaceae*, etc) but in the latter order leaves are not gland-dotted.

Examples. Useful Plants: *Citrus*[1] (e.g. lime, lemon, orange, citron

harmala (B. ISBAND; H. HARMAL)—seeds yield Turkey-red, *Micromelum pubescens*—an evergreen tree, etc.; **other common plants:** rue (*Ruta graveolens*, B. ERMUL; H. SADAB)—a strongly smelling small herb, *Glycosmis arborea, Clausena heptaphylla, C. pentaphylla* (B. & H. PANKARPUR), *Luvunga scandens*—a large thorny climbing shrub, *Toddalia* (B TODALI; H. DAHAN)—a large prickly climbing shrub, *Xanthoxylum* (B. BAZINALI; H. BADRANG)—a prickly tree, etc.

[1]Common species of *Citrus*: sour lime (*C. aurantifolia*; B. PATI- or KAGZI-NEBU; H. NIMBOO), sweet lime (*C. limetta*; B. MITHA-NEBU or -KAGZI), lemon (*C. limon*; B. NEBU; H. KHATTI), rough lemon (*C. jambhiri*; B. JAMIR; H. JHAMBHIRI), *C. assamensis* (B. ADA-JAMIR)—used for garnishing curries, citron (*C. medica*; B. BARA-NEBU; H. BARA-NIMBOO), pummelo or shaddock (*C. grandis*; B. BATABI-NEBU; ' —loose in prep... bique, and Valentia are varieties of it)—tight-skinned, king orange (*C. nobilis*), wild orange (*C. indica*)—growing wild in Assam, bergamot orange (*C. bergamia*) —bergamot oil is prepared from it, and grapefruit (*C. paradisi*).

FAMILY 15 *Meliaceae* (*750 sp.—58 sp. in India*)

Habit—mostly trees, rarely shrubs. Leaves pinnately compound, leaflets oblique. Inflorescence an axillary panicle. Flowers regular, often bisexual, sometimes polygamous (as in *Amoora*), hypogynous, Calyx—sepals (4-5), gamosepalous. Corolla —petals 4-5, usually polypetalous, imbricate. Androecium—stamens 8-10, generally united into a long or short staminal tube. Gynoecium — carpels (2-5), syncarpous; ovary superior, 2- to 5-locular, rarely 1-locular, with 1 or 2 ovules in each, seldom more; disc annular surrounding the ovary. Fruit a capsule, berry or drupe. Seed often winged, albuminous.
Floral formula—$\oplus$ ⚥ $K_{(4-5)}C_{4-5}A_{(8-10)}\underline{G}_{(2-5)}$.

Examples. Ti[illegible]
e.g. toon (*C. to*[illegible]
timber moderately hard, [illegible]

doors and windows, margosa (*Azadirachta indica*=*Melia azadirachta*; B. & H. NEEM)—also medicinal, Persian lilac (*Melia azedarach*; B. GHORA-NEEM)—also yields firewood, *Walsura robusta* (B. LALI)—heartwood brown or light red, *Dysoxylum procerum* (B. LALI)—heartwood bright red and *Chikrassia tabularis* —wood hard and suitable for planking and furniture.

FAMILY 16 *Rhamnaceae (500 sp.—51 sp. in India)*

Habit—trees, shrubs and climbers. **Leaves** simple, alternate or rarely opposite, stipulate (sometimes spinous). **Inflorescence** an axillary cyme (often paniculate). **Flowers** small and inconspicuous, regular, bisexual or sometimes unisexual, usually pentamerous, sometimes tetramerous, perigynous (with the receptacle cup-shaped) to epigynous (with the receptacle united with the ovary); disc well developed (intrastaminal). **Calyx**—sepals (5-4), gamosepalous, valvate. **Corolla** —petals 5-4, polypetalous, often very small, clawed at the base and hooded above, sometimes absent. **Androecium**—stamens 5-4, opposite to and often enclosed by the petals. **Gynoecium**—carpels (3), syncarpous; ovary superior, free or immersed in fleshy disc, 3-locular, sometimes 2- or 1-locular, with 1 basal ovule in each. **Fruit** varying, a drupe or a nut or a dry one splitting into mericarps. **Seed** with thin endosperm. *Floral formula*—$\oplus$ ⚥ $K_{(5-4)}C_{5-4}A_{5-4}\underline{G}_{(3)}$.

Rhamnaceae is closely related to *Vitaceae*; the chief characters of *Rhamnaceae* distinguishing it from *Vitaceae* are: simple leaves (sometimes with spines), very small petals, structure of receptacle (free from or united with the ovary), ovary often sunken in receptacle or disc, fruit sometimes drupaceous, etc.

Examples. *Zizyphus* (40 sp.—14 in India), e.g. Indian plum or jujube (*Z. jujuba*)—a tree with edible fruits, *Z. oenoplia*—a sturdy shrub or undershrub, *Z. nummularia* and *Z. vulgaris* are shrubs found in Punjab, *Gouania leptostachya*—a strong tendril-climber, *Rhamnus nepalensis*—a rambling shrub, *Ventilago maderaspatana*—a strong hook-climber, etc.

FAMILY 17 *Sapindaceae (1,000 sp.—46 sp. in India)*

Habit—trees, shrubs or lianes climbing by axillary tendrils which are often closely coiled. Balloon vine (*Cardiospermum*), however, is a slender tendril-climber (see FIG. I/36). The family shows anomalous secondary growth **Leaves** alternate, . **Inflorescence** cymose. **Flowers** very xual, monoecious, or bisexual, gene- ous, sometimes 4-merous, male flower often with rudimentary ovary, and female flower often with staminode. **Calyx**—sepals 5, sometimes 4, usually polysepalous, imbricate. **Corolla**—petals 5, often 4 in regular flowers by the suppression of 1, free, imbricate, petals often with scales or tufts of hairs; an annular disc often present between the corolla and the androecium. **Androecium**—stamens often 8 by the suppression of 2, sometimes fewer in number, often inserted within the disc around the ovary. **Gynoecium**—carpels (3), syncarpous; ovary 3-locular, superior, with one ovule in each chamber. **Fruit**—dry

(capsule or nut) or fleshy (berry or drupe), sometimes a schizocarp. Seed often arillate, exalbuminous; embryo curved.
Floral formula—⊕ or ·|· ♂·♀ $K_{5-4}C_{5-4}A_{4+4}G_0 | A_0 \underline{G}_{(3)}$.

Examples. Litchi (*Nephelium litchi*)—the edible part is the fleshy aril, longan (*N. longana*)—aril edible, soap-nut (*Sapindus trifoliatus* and *S. mukorossi*)—fruits contain saponin which makes a lather with water and is used for washing silk and woollen fabrics, balloon vine (*Cardiospermum halicacabum*)—a common weed (see FIG. I/36), *Allophylus cobbe*—a shrub or small tree. *Aphania danura*—common in village shrubberies, *Dodonaea viscosa*—commonly grown as a hedge plant *Schleichera trijuga*—furnishes the best Mirzapur lac and is also a valuable timber tree, etc.

FAMILY 18 *Anacardiaceae* (*500 sp.—58 sp. in India*)

Habit—shrubs or trees, with often conspicuous resin. **Leaves** simple or pinnately compound, alternate, exstipulate. **Inflorescence** a panicle of many small flowers. **Flowers** small, regular, bisexual, sometimes polygamous, hypogynous to epigynous, typically pentamerous; disc present. **Calyx**—sepals usually 5, sometimes varying from 3 to 7, free or united. **Corolla**—petals as many as sepals, sometimes absent, free or connate. **Androecium**—stamens 10-5 (fertile stamens in many cases varying in number, as in *Anacardium* and *Mangifera* where only one stamen is fertile), free, inserted on an annular disc. **Gynoecium**—carpels commonly (3-1), rarely (5), syncarpous; ovary superior or sometimes inferior, often 1-celled, rarely 2- to 5-celled, with one ovule in each, often only one ovule matures into seed. **Fruit** commonly a 1-celled and 1-seeded drupe. **Seed** exalbuminous, with a large curved embryo. *Floral formula*—⊕ ⚥ $K_5C_5A_{10-5}\underline{G}_{(3-1)}$.

[illegible] *[illegible]acardium* [illegible] pistachio [illegible] *[illegible]na wodier*, *Buchanania latifolia*, *Tapiria hirsuta* and *Rhus* (130 sp.—11 in India, common in the Eastern and Western Himalayas)—some species are useful while others are poisonous.

FAMILY 19 *Leguminosae*[1] (*12,000 sp.—951 sp. in India*)

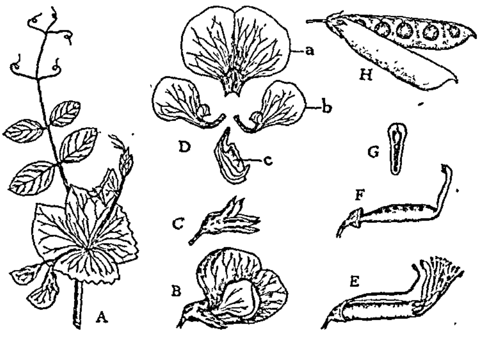
Habit—herbs, shrubs, trees and climbers. **Roots** of many species, particularly of *Papilionaceae*, have tubercles (see FIG. III/5). **Leaves** alternate, pinnately compound, rarely simple, as in rattlewort (*Crotalaria sericea*), camel's foot tree (*Bauhinia*) and some species of *Desmodium*, e.g. *D. gangeticum*, with a swollen leaf-base known as

[illegible] *[illegible]pinіaceae*, *Mimosaceae* and *Papilionaceae*.

the pulvinus; stipules 2, usually free. **Flowers** bisexual and complete, regular or zygomorphic or irregular, hypogynous or slightly perigynous. **Calyx**—sepals usually (5) with the odd one anterior (away from the axis), sometimes (4), united or free. **Corolla**—petals usually 5 with the odd one posterior (towards the axis), sometimes 4, free or united. **Androecium**—stamens usually 10 or numerous, sometimes less than 10 by abortion, free or united. **Gynoecium**—carpel 1; ovary 1-celled, with 1 to many ovules, superior; placentation marginal; ovary often on a long or short stalk, called stipe or gynophore. **Fruit** a legume or pod.

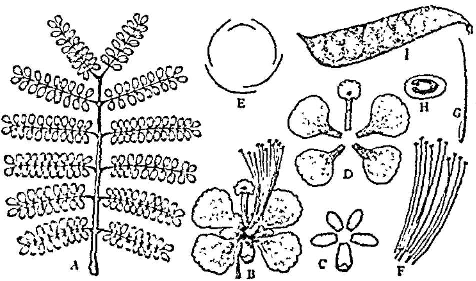
This is the second biggest family among the dicotyledons (being second only to *Compositae*), with varying characters, and as such it has been divided into the following sub-families. The division is primarily based on the characters of the corolla and the stamens (see FIG. 2). All these sub-families are well represented in India. From an economic standpoint this is one of the most important families (see pp. 597-9); probably it ranks second to *Grammaceae* in order of importance.

(1) *Papilionaceae* (754 sp. in India). Herbs, shrubs, trees and climbers. Leaves unipinnate, often trifoliate, rarely simple; stipels often present. **Inflorescence** usually a raceme. **Flowers** zygomorphic,



polypetalous and papilionaceous. Calyx—sepals usually (5), gamosepalous, often imbricate, sometimes valvate. Corolla—petals usually 5, free, of very unequal sizes, the posterior largest one being the [illegible] or monadelphous, as in coral tree (*Erythrina*). *Floral formula*—·|· ⚥ $K_{(5)}C_5A_{(9)+1}\underline{G}_1$. For floral diagram see p. 577.

(2) *Caesalpinieae* (110 sp. in India). Shrubs and trees, rarely climbers or herbs. Leaves unipinnate or bipinnate, rarely simple, as in camel's foot tree (*Bauhinia*); stipels absent. Inflorescence commonly a raceme. Flowers zygomorphic or irregular and polypetalous. Calyx—sepals usually 5, polysepalous (sometimes gamosepalous), imbricate. Corolla—petals usually 5, free, sub-equal or unequal, the odd or posterior one (sometimes very small) always innermost; aestivation of corolla imbricate. Androecium—stamens ten or fewer by abortion, free. *Floral formula*—·|· ⚥ $K_5C_5A_{10}\underline{G}_1$. For floral diagram see p. 577.

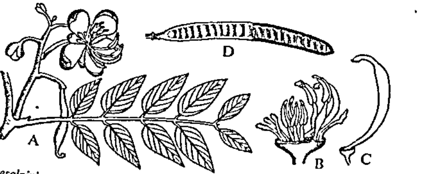


Caesalpinieae. FIG. 18. Dwarf gold mohur (*Caesalpinia pulcherrima*). *A*, a pinnately compound leaf; *B*, a flower; *C*, calyx; *D*, corolla—petals dissected out; *E*, aestivation (imbricate); *F*, stamens; *G*, pistil (one carpel); *H*, ovary in transection showing marginal placentation; and *I*, a fruit.

(3) *Mimoseae* (87 sp. in India). Shrubs and trees, sometimes herbs. Leaves bipinnate; stipels present or absent. Inflorescence a head or a spike. Flowers regular, often small and aggregated in spherical heads. Calyx—sepals (5) or (4), generally gamosepalous, valvate. Corolla—petals (5) or (4) mostly gamopetalous; aestivation of corolla valvate. Androecium—stamens mostly numerous, sometimes 10, 5

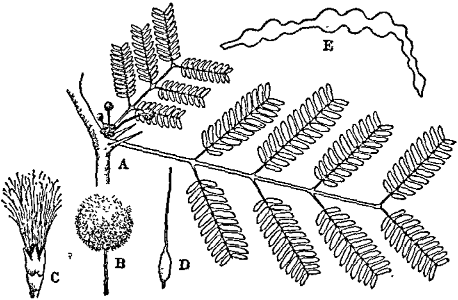
or 4 (as in *Mimosa*, *Entada*, *Neptunia* and *Prosopis*), free, sometime united at the base; pollen often united in small masses. *Floral formula*— ⊕ ⚥ $K_{(5-4)}C_{(5-4)}A_{\infty,10,8\text{ or }4}\underline{G}_1$. For floral diagram see p. 577. [illegible] e of the largest genera are *Crota*[illegible] [illegible].), *Trifolium* (290 sp.), *Desmodium* [illegible] sp.), *Lathyrus* (110 sp.), etc. **Useful plants**: pulses (rich in proteins): gram (*Cicer arietinum*), lentil (*Lens culinaris*), pigeon pea (*Cajanus cajan*), pea (*Pisum sativum*), green gram (*Phaseolus aureus*), black gram (*P. mungo*), *Lathyrus sativus*, soybean (*Glycine max*), broad bean (*Vicia faba*), etc.; vegetables: country bean (*Dolichos lablab*), cow pea (*Vigna sinensis*), sword bean (*Canavalia gladiata*), French bean (*Phaseolus vulgaris*), etc.; natural fertilizers: *Sesbania cannabina* (B. DHAINCHA), sesban (*S. sesban*; B. JAINTI; H. JAINT), lucerne or alfalfa (*Medicago sativa*)—also an excellent fodder, *Tephrosia candida* and *Derris robusta* grown in tea gardens, etc.; timber trees: Indian redwood (*Dalbergia sissoo*) and Indian rosewood (*D. latifolia*); other useful plants: groundnut or peanut (*Arachis hypogaea*; see FIG. III/49), pith plant (*Aeschynomene indica*), Indian hemp (*Crotalaria juncea*), fenugreek (*Trigonella*; B. METHI), indigo (*Indigofera*), *Derris elliptica*—a woody climber, roots used as a valuable insecticide and also used for poisoning fishes in tanks, Indian liquorice or crab's eye (*Abrus precatorius*), sweet pea (*Lathyrus odoratus*)—ornamental, lupin (*Lupinus*)—ornamental and a fodder, red sandalwood (*Pterocarpus santalinus*), *Pongamia glabra*—a shade tree, etc.; other common plants: rattlewort (*Crotalaria sericea*), butterfly pea (*Clitoria ternatea*), *Sesbania grandiflora* (B. BAKPHUL; H. AGAST), coral tree (*Erythrina indica*), flame of the forest (*Butea monosperma*), Indian telegraph plant (*Desmodium gyrans*), *D. gangeticum*, cowage (*Mucuna pruriens*)—fruits with stinging hairs, wild pea (*Lathyrus aphaca*), wild indigo (*Tephrosia purpurea*), etc.

Examples of *Caesalpinieae*. *Cassia* with 400 species and *Bauhinia* with 250 species are the largest genera. **Useful plants**. tamarind



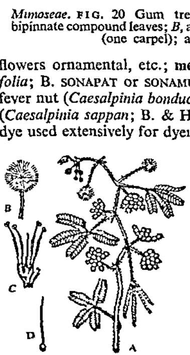
Caesalpinieae. FIG. 19. *Cassia sophera*. *A*, a branch with inflorescence; *B*, stamens and pistil; *C*, pistil (one carpel); and *D*, a fruit partially opened up.

(*Tamarindus indica*)—fruits widely used for sour preparations, Indian laburnum (*Cassia fistula*)—heartwood very hard and durable, and



Mimoseae. FIG. 20 Gum tree (*Acacia arabica*). *A*, a branch with bipinnate compound leaves; *B*, an inflorescence (head); *C*, a flower; *D*, pistil (one carpel); and *E*, a fruit (lomentum).

flowers ornamental, etc.; **medicinal**: Indian senna (*Cassia angustifolia*; B. SONAPAT or SONAMUKHI; H. SANAKKAPAT). *Saraca indica*, fever nut (*Caesalpinia bonducella*), etc.; **dye**: sappan or Brazil wood (*Caesalpinia sappan*; B. & H. BAKAM)—wood yields a valuable red dye used extensively for dyeing silk and wool, starch coloured with this dye forms 'ABIR' used in 'HOLI' festival, and pods yield a high percentage of tannin; **ornamental**: camel's foot tree (*Bauhinia purpurea* and *B. variegata*), gold mohur (*Delonix regia*; see FIG. I/91), dwarf gold mohur or peacock flower (*Caesalpinia pulcherrima*; FIG. 18), Jerusalem thorn (*Parkinsonia aculeata*) and *Peltophorum*; **other common plants**: *Cassia sophera*, *C. occidentalis*, ringworm shrub (*C. alata*), *C. tora*, etc.



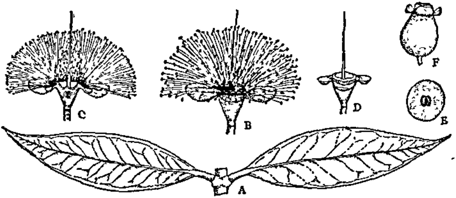
Mimoseae. FIG. 21. Sensitive plant (*Mimosa pudica*). *A*, a branch; *B*, an inflorescence; *C*, a flower; and *D*, pistil (one carpel).

Examples of *Mimoseae*. Useful plants: *Acacia* (500 sp.), e.g. catechu (*Acacia catechu*)—catechu, a kind of tannin, is obtained by boiling chips of heartwood, *A. arabica* and *A. senegal* yield

(*F. indica*), apple (*Malus sylvestris*), pear (*Pyrus communis* and *P. pyrifolia*), *Potentilla* (300 sp.), e g. silverweed (*Potentilla fulgens*)—common in the hills, raspberry (*Rubus idaeus*), wild raspberry (*R. moluccanus*), and many other wild species in the hills.

FAMILY 21 *Myrtaceae (2,800 sp —112 sp. in India)*

Habit—shrubs and trees, rarely herbs; bicollateral bundles or internal phloem often present. Leaves simple, opposite, gland-dotted. **Inflorescence** cymose. **Flowers** regular, epigynous, bisexual; disc lining the calyx-tube. **Calyx**—sepals *4-5, free*, or (4-5), connate, persistent or deciduous, valvate or imbricate. **Corolla**—petals 4-5, free, imbricate. **Androecium**—stamens numerous (rarely few), free, sometimes polyadelphous, epigynous. **Gynoecium**—carpels (2-5) or (∞), syncarpous; ovary crowned by a disc, inferior (or sometimes half-inferior), 1- to 2-locular, sometimes multilocular, with 2 to many ovules in each loculus; placentation axile (rarely parietal) Fruit a berry or capsule, inferior, usually with persistent calyx. Seed exalbuminous *Floral formula*—$\oplus$ ⚥ $K_{4-5 \text{ or } (4-5)} C_{4-5} A_{\infty} \bar{G}_{(2-5) \text{ or } (\infty)}$.



Myrtaceae. FIG. 23. Rose-apple (*Syzygium jambos*). *A*, opposite leaves, *B*, a flower; *C*, a flower cut longitudinally; *D*, pistil; *E*, section of ovary showing axile placentation; and *F*, a fruit

Examples. Useful plants: *Eucalyptus* (230 sp.)—leaves yield eucalyptus oil, guava (*Psidium guayava*), *Syzygium* (140 sp), e g. clove (*S. aromaticum*), black-berry (*S. cuminii*; B. KALA-JAM; I JAM), rose-apple (*S. jambos*; B. G· *malaccense*; B. JAMRUL), allspice (fruits form allspice which combines the flavour of cloves, nutmeg and cinnamon, cajeput (*Melaleuca*)—leaves yield cajeput oil, etc ; other common plants: *Barringtonia acutangula* (B. & H. HIJAL), myrtle (*Myrtus communis*), bottlebrush tree (*Callistemon linearis*), etc.

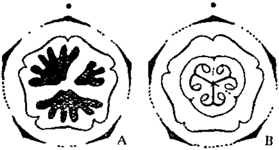
FAMILY 22 *Cucurbitaceae (800 sp.—84 sp. in India)*

Habit—tendril climbers; tendrils extra-axillary, simple or branched. **Leaves** simple, alternate and palmately veined. **Flowers** regular, unisexual, epigynous and monoecious or dioecious. **Calyx**—*sepals*

(5), united, often deeply 5-lobed. **Corolla**—petals (5), united, often deeply 5-lobed, imbricate; inserted on the calyx-tube

Male Flowers: **androecium**—stamens usually 3, sometimes 5, varying in character; sometimes they are free but more commonly they are united in a pair (or in 2 pairs when stamens 5) throughout their whole length (*synandrous*), the odd one remaining free; in some cases the anthers only are united (*syngenesious*); each anther 1-lobed or 2-lobed; paired stamens have either 2-lobed or 4-lobed anthers; anther-lobes variously folded, or *sinuous*, i.e. twisted like a transverse 'S'. Rudiments of the pistil sometimes present.

FIG. 24. Floral diagrams of *Cucurbitaceae*. *A*, male flower; *B*, female flower.



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ovules many; style 1; stigmas 3 which are often forked. Fruit a pepo. *Floral formula*—$\oplus$ ♂ ♀ or ♂-♀ $K_{(5)}C_{(5)}A_{3 \text{ or } 5}\, G_0 \mid A_0\overline{G}_{(3)}$.

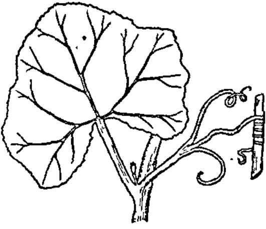


FIG. 25

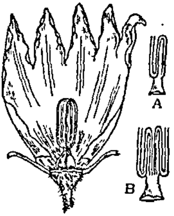


FIG. 26

Cucurbitaceae. FIG. 25. Gourd (*Cucurbita pepo*) Portion of a branch with a leaf and a tendril. FIG. 26. Male flower of the same. *A*, one stamen; *B*, two stamens united together.

The systematic position of *Cucurbitaceae* is disputed. There is controversy also regarding the nature of placentation (axile or parietal) and of tendrils. Bentham

and Hooker have placed *Cucurbitaceae* and *Passiflorae* together in the same cohort (order) Passiflorales among polypetalous orders, not considering them as advanced, on the basis of the following characters: tendrils, regular flowers (gamopetalous or polypetalous), syncarpous pistil, 1-locular ovary, parietal placentation, etc. *Passiflorae*, however, is distinguished from *Cucurbitaceae* by its stipulate leaves, axillary tendrils, mostly bisexual flowers, often androgynophore and corona, free stamens, superior ovary, etc. Engler, however, considers *Cucurbitaceae* as a much advanced family and places it in Sympetalae as an only family of Cucurbitales prior to *Campanulaceae* and close to *Compositae*. Hutchinson has likewise separated the two families into two orders Cucurbitales and Passiflorales but regarding their systematic position he seems to have shared the same view as Bentham and Hooker. There is no doubt that *Cucurbitaceae* is closely related to *Campanulaceae*, the relationship being based on pentamerous symmetry, gamopetaly, epigyny, reduction in the number of stamens and carpels and syngenesious stamens (sometimes also found in *Campanulaceae*).

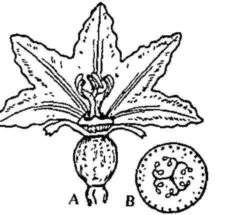


FIG 27. *A*, female flower of *Cucurbita pepo*; *B*, ovary in transverse section showing placentation.

Examples. Sweet gourd or musk melon (*Cucurbita moschata*), pumpkin or vegetable marrow (*C. pepo*; B. KUMRA; H. HALWAKADDU)—squash is a variety of it, giant pumpkin (*C. maxima*), snake gourd (*Trichosanthes anguina*), *T. dioica* (B. PATAL; H. PARWAL), bitter gourd (*Momordica charantia*; B. UCHCHE and KARALA; H. KARELI), *M. cochinchinensis* (B. KAKROL; H. CHATTHAI), ash or wax gourd (*Benincasa cerifera*), ribbed gourd (*Luffa acutangula*), bath sponge or loofah (*L. cylindrica*), *Coccinia cordifolia* (B. TELAKUCHA; H. BHIMBA), chayote (*Sechium edule*), cucumber (*Cucumis sativus*), melon (*C. melo*), water melon (*Citrullus vulgaris*), colocynth (*C. colocynthis*; B. MAKAL; H. INDRAYAN)—medicinal, and *Bryonia*—medicinal.

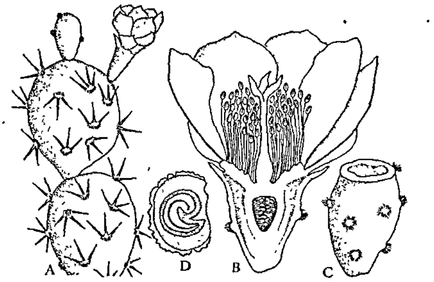
FAMILY 23 *Cactaceae* (*1,500 sp.—6 sp. in India*)

often very deep. (Anatomically abundant water-storing parenchyma, mucilage-

containing cell-sap, thick cuticle, mechanical tissues in the ridges, sunken stomata, etc., are characteristic of this family.) Flowers often solitary, sometimes very large, often brightly coloured, but white in night-blooming cacti, regular, bisexual, epigynous. Perianth—tepals many, often united to form a tube, spirally arranged, showing a gradual transition from sepaloid to petaloid stages. Androecium—stamens numerous, often epiphyllous. Gynoecium—carpels (3-∞), united; ovary inferior, 1-chambered, with 3-∞ parietal placentae bearing numerous anatropous ovules; style simple; stigmas correspond to the number of placentae Fruit a many-seeded berry, sometimes edible. Seed with or without endosperm. *Floral formula*—$\oplus$ ⚥ $\overline{P_{(\infty)}A_{\infty}}\bar{G}_{(3-\infty)}$.

Cactaceae. FIG. 28. *A*, *Cereus triangularis*; *B*, *Phyllocactus latifrons.*

The affinity of *Cactaceae* is difficult to trace. Bentham and Hooker have placed *Ficoideae* (*Aizoaceae* of Engler) and *Cactaceae* in one cohort. There may be a distant affinity of *Cactaceae* with



Cactaceae. FIG. 29. Prickly pear (*Opuntia dillenii*). *A*, plant (portion) with flower, thorns and bristles; *B*, flower cut longitudinally; *C*, fruit; *D*, seed cut longitudinally showing curved embryo.

Aizoaceae. Engler has separated the two families, and placed *Cactaceae* under the order Opuntiales close to Myrtiflorae with which the former has some affinity in floral structure, particularly stamens and inferior ovary. Some cacti bear external resemblances to certain species of *Euphorbia* in general habit but are readily distinguished from them *by having no latex.*

Examples. *Opuntia* (250 sp.), e g. prickly pear (*O. dillenii*; FIG 29)—a troublesome weed, sometimes bearing edible fruit, *Rhipsalis cassytha*—a small fleshy shrub in Madhya Pradesh, *Nopalia*—similar to *Opuntia* but smaller in size, night-blooming cacti (*Cereus, Phyllocactus*, etc), *Cereus grandiflorus*—flowers sweet-scented, *C. giganteus*—largest of all cacti, *C. hexagonus, C. multangularis* and *C. tetragonus*—commonly grown as hedge plants, *C. triargularis* (FIG. 28A)—a climber, etc, *Phyllocactus latifrons*—flat-stemmed (FIG. 28B), *Echinocactus, Melocactus, Epiphyllum* (see FIG. I/38C), *Pereskia bleo*—a thorny shrub with flat green leaves. Indigenous cacti are very few but a good number of exotic species are grown in Indian gardens as ornamental plants.

FAMILY 24 *Umbelliferae (2,700 sp.—176 sp. in India)*

Habit—herbs (rarely shrubs); stem usually fistular. **Leaves** alternate, simple, often much divided, sometimes decompound; petiole usually sheathing at the base. **Inflorescence** an umbel, usually compound or in a few cases simple as in *Centella.* **Flowers** regular (actinomorphic) or sometimes zygomorphic, epigynous, bisexual or polygamous, outer flowers sometimes rayed; mostly protandrous; bracts in the form of an involucre. **Calyx**—sepals 5, free, adnate to the ovary, often considerably reduced in size. **Corolla**—petals 5, rarely absent, free, adnate to the ovary, sometimes unequal, margin often incurved, valvate or imbricate. **Androecium**—stamens 5, free, alternating with the petals, epigynous; filaments bent inwards in the bud; anthers introrse. **Gynoecium**—carpels (2), syncarpous; ovary inferior, 2-celled, crowned by a 2-lobed epigynous disc (stylopodium) with two free styles arising from it; stigmas capitate; ovules 2, solitary in each cell, pendulous. **Fruit** a cremocarp consisting of two indehiscent carpels laterally or dorsally compressed, breaking up into two parts, called *mericarps*, which remain attached to a slender, often forked axis (*carpophore*); each mericarp usually shows five longitudinal ridges and oil-canals (*vittae*) in the furrows. **Seeds** 2, solitary in each mericarp, albuminous. *Floral formula*—⊕ or ·|· ⚥ $K_5C_5A_5\overline{G}_{(2)}$.

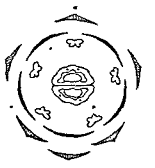
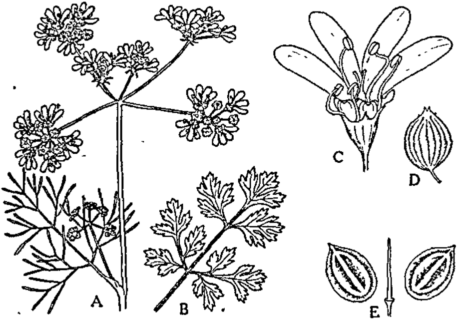


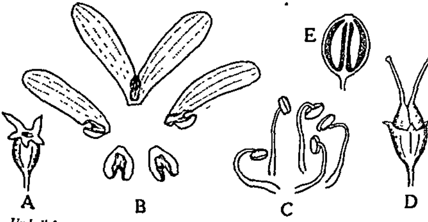
FIG 30. Floral diagram of *Umbelliferae.*

Floral Range in *Umbelliferae.* Flowers commonly in a compound umbel, sometimes in a compact mass (head) as in *Eryngium,* or sometimes in a simple umbel or even single, as in some species of *Hydrocotyle* (= *Centella*). Flowers regular or zygomorphic, bisexual or polygamous but always epigynous. Flower development

is, however, peculiar: stamens appear first, then petals followed by sepals, last of all the two carpels—at first separate but later united; the receptacle grows round the ovary which then becomes inferior. Disc variously 2-lobed Sepals adnate to ovary, 5-toothed or entire or reduced to a few scales or to a narrow circular



Umbelliferae. FIG. 31. *Coriander* (*Coriandrum*). *A*, a branch with leaf and compound umbels; *B*, a lower leaf; *C*, a flower, *D*, a fruit; and *E*, a fruit split into two mericarps, and the carpophore (central axis)



Umbelliferae (contd.). FIG. 32. *A*, calyx with inferior ovary; *B*, petals dissected out; *C*, stamens dissected out; *D*, pistil with two styles, bilobed disc, calyx-teeth and inferior ovary; and *E*, ovary in longitudinal section.

variety of forms and help identification of genera and species.

Umbelliferae maintains a connexion with *Compositae* by the following characters: herbaceous nature of plants, reduction of calyx, presence of involucre, dense inflorescence (a near approach to capitulum of *Compositae*), outer flowers often sterile and rayed, bicarpellate pistil with two distinct styles, inferior ovary, solitary ovule in the ovarian chamber, etc. The fruit characters, however, readily distinguish the two families.

Examples. Useful plants: condiments and spices: coriander (*Coriandrum sativum*), anise or fennel (*Foeniculum vulgare*), *Carum copticum* (B. JOWAN; H. AJOWAN), *C. roxburghianum* (B. RANDHANI), caraway (*C. carui*; B. & H. SHIAJIRA), cumin (*Cuminum cyminum*; B. JIRA; H. SAFED-JIRA), parsnip (*Peucedanum sowa*; B. SULPA; H. SOWA), etc.; **vegetables:** carrot (*Daucus carota*) and celery (*Apium graveolens*); **medicinal:** asafoetida (*Ferula asafoetida*; B. & H. HING)—asafoetida (HING) of commerce is obtained from the roots; **other common plants:** wild coriander (*Eryngium foetidum*), Indian pennywort (*Centella asiatica*), *C. rotundifolia*, dropwort (*Oenanthe*)—a common weed of wet places, etc.

SUB-CLASS II GAMOPETALAE

FAMILY 25 *Rubiaceae* (*5,500 sp.—489 sp. in India*)

Habit—herbs (erect or prostrate), shrubs, trees and climbers, sometimes thorny. **Leaves** simple, entire, opposite (decussate) or whorled, with interpetiolar (sometimes intrapetiolar) stipules. **Inflorescence**—typically cymose, frequently dichasial. **Flowers** regular, bisexual, epigynous, sometimes dimorphic, as in some species of *Randia* and *Oldenlandia*. **Calyx**—sepals usually (4), sometimes (5), gamosepalous,

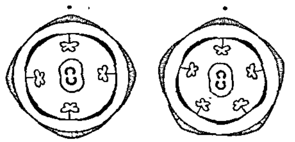


FIG. 33. Floral diagrams of *Rubiaceae*.

calyx-tube adnate to the ovary. **Corolla**—petals usually (4), sometimes (5), gamopetalous, generally rotate; aestivation valvate, imbricate or twisted. **Androecium**—stamens as many as petals, epipetalous, inserted within or at the mouth the corolla-tube, alternating with the corolla-lobes. **Gynoecium**—carpels (2), syncarpous; ovary inferior, commonly 2-locular, with 1-∞ ovules in each; disc usually annular, at the base of the style. **Fruit** a berry, drupe or capsule. **Seed** with fleshy or horny endosperm. *Floral formula*— $\oplus$ ⚥ $K_{(4-5)}\overline{C_{(4-5)}A}_{4-5}\overline{G}_{(2)}$.

Rubiaceae is related to *Caprifoliaceae* but in the latter the interpetiolar stipules are wanting and the carpels are (5-3). *Rubiaceae* is also distantly related to *Compositae* by head or capitulum, as in *Anthocephalus*, *Uncaria*, *Nauclea*, *Adina*, etc.

Examples. Useful plants: medicinal: *Cinchona* yields quinine which is extracted from root- and stem-barks, ipecac (*Cephaelis ipecacuanha*) yields emetine, *Oldenlandia corymbosa*, *Paederia foetida*, etc.; **ornamental:** *Ixora* (200 sp.), e.g. *I. coccinea*, *I. parviflora*, etc., *Gardenia florida*, *Pavetta indica*, *Anthocephalus cadamba* (B. & H. KADAM), *Adina cordifolia* (B. KELI-KADAM), *Cephalanthus* (B. PANI-KADAM), *Randia*, *Mussaenda* (see FIG. 1/100), etc.; **dye:** madder (*Rubia cordifolia*) and *Morinda tinctoria*; **beverage:** coffee (*Coffea arabica* and *C. robusta*)—*seeds are the source of coffee powder*; **other common plants:** *Coffea bengalensis*, *Oldenlandia diffusa*, *Dentella repens*, etc.—all growing wild, *Vangueria spinosa*—a thorny shrub, *Uncaria* (see FIG. 1/17B)—a thorny climber, *Galium* (250 sp.)—common in the hills, etc.

FAMILY 26 *Compositae* (*14,100 sp.—674 sp. in India*)

Habit—herbs and shrubs, sometimes with internal phloem; some species with latex. **Leaves** simple, alternate or opposite, rarely compound. **Inflorescence** a head (or capitulum), with an involucre of bracts. **Flowers** (florets) are of two kinds—the central ones (called *disc florets*) are tubular, and the marginal ones (called *ray florets*) are ligulate; sometimes all florets are of one kind—either tubular or ligulate.

Disc Florets: regular, tubular, bisexual and epigynous, each usually in the axil of a bracteole. **Calyx** often modified into a cluster of hairs called pappus, as in *Tridax* and *Ageratum*, or into scales, as in sunflower and *Eclipta*, or absent, as in watercress (*Enhydra*). **Corolla**—petals (5), gamopetalous, tubular. **Androecium**—stamens 5, epipetalous, filaments free but anthers united (syngenesious). **Gynoecium**—carpels (2), syncarpous; ovary inferior, 1-celled, with one basal, anatropous ovule; style 1; stigmas bifid. **Fruit** a cypsela. *Floral formula*—$\oplus$ ⚥ Kpappus or 0 $\overline{C_{(5)}A_{(5)}}\bar{G}_{(2)}$.

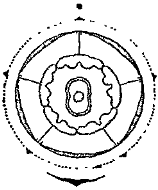
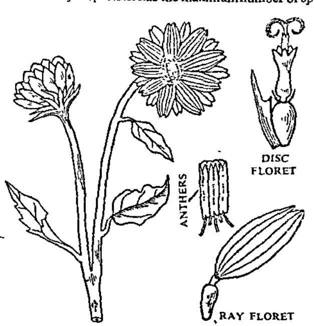


FIG. 34. Floral diagram of *Compositae* (disc floret).

Ray Florets: zygomorphic, ligulate, unisexual (female) or sometimes neuter, as in sunflower, and epigynous, each usually in the axil of a bracteole. **Calyx** usually modified into pappus, sometimes it is scaly or absent. **Corolla**—petals (5), gamopetalous, ligulate (strap-shaped). **Gynoecium**, as in the disc florets. **Fruit** the same. *Floral formula*—·|· ♀ Kpappus or 0 $C_{(5)}\bar{G}_{(2)}$.

Systematic Position of ***Compositae.*** For its many special characters *Compositae*

dicate that the genus *Senecio* came into existence first and other genera developed from it in due course It is likely *Compositae* and *Rubiaceae* have arisen from a common ancestry. The former also maintains a phylogenetic connexion with *Umbelliferae* through inflorescence and floral mechanism. *Compositae* is remarkable in many respects: it has the maximum number of species among dicotyledons,



Compositae. FIG. 35. Sunflower (*Helianthus annuus*). Note the branch with inflorescences (heads), disc floret (bisexual), anthers (syngenesious) and ray floret (neuter or female).

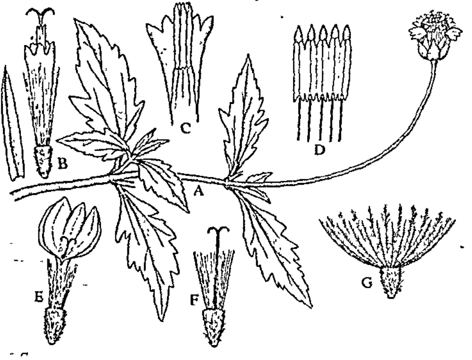
and some genera with very large number of species, e g. *Senecio* (2,500 sp.),

in a head (a perfect type of inflorescence) with the following decided advantages —(*a*) greater conspicuousness to attract insects for cross-pollination; (*b*) considerable saving of corolla-material; and (*c*) achievement of cross-pollination by a single insect within a very short time; (3) very simple but effective type of floral mechanism to achieve cross-pollination without at the same time losing a chance for self-pollination if the former method fails; (4) easy access of insects to the nectary which lies at the base of the style and is protected from rain; (5) flowers

(7) very effective mechanism for seed- (fruit-) distribution by parachute-like pappus (calyx) or by hooks or glands developing on the fruit.

Examples. Useful plants : medicinal: Indian wormwood (*Artemisia vulgaris*; B. NAGDONA; H. NAGDUNA), santonin (*A. cina*), *Vernonia*

anthelmintica (B. SOMRAJ; H. KALIZIRI), *Eupatorium ayapana* (B. AYAPANA), *Wedelia calendulacea*, *Eclipta alba*, etc.; vegetables: chicory



(*Cichorium intybus*; H. KASNI), endive (*C. endivia*), lettuce (*Lactuca sativa*), globe artichoke (*Cynara*), Jerusalem artichoke (*Helianthus tuberosus*; B. HATICHOKE), etc.; oils: safflower (*Carthamus tinctorius*)—also a source of dye, sunflower (*Helianthus annuus*; FIG. 35), etc.; insecticides: a few species of *Chrysanthemum* (*Pyrethrum*), e.g. *C. cinerariefolium* yielding more or less 1% pyrethrin; ornamental: sunflower, *Zinnia*, *Cosmos*, *Dahlia*, daisy (*Bellis*), *Calendula*, *Chrysanthemum*, *Aster*, *Gerbera*, marigold (*Tagetes patula*), everlasting flower (*Helichrysum*), etc.; other common plants: goat-weed (*Ageratum conyzoides*) with purplish heads, *Blumea lacera*, globe thistle (*Echinops*), *Eupatorium odoratum*—a common scandent shrub, *Enhydra fluctuans*, elephant's foot (*Elephantopus scaber*), *Sonchus*—an annual weed with latex, *Tridax procumbens* (FIG. 36), cockle-bur (*Xanthium strumarium*), *Mikania scandens*—a twiner, *Vernonia cineria*—a herb and *V. arborea*—a tree.

FAMILY 27 *Apocynaceae (1,400 sp.—67 sp. in India)*

Habit—herbs, shrubs, trees, twiners and lianes; with latex: bicollateral bundles or internal phloem often present. Leaves simple, oppo-

site or whorled, rarely alternate. Flowers regular, bisexual and hypogynous, in cymes, usually salver- or funnel-shaped, often with corona.

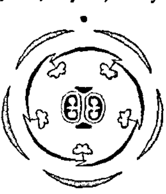
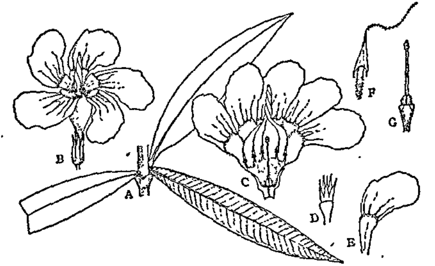


FIG. 37. Floral diagram of *Apocynaceae*.

Calyx—sepals (5), rarely (4), gamosepalous, imbricate. Corolla—petals (5), rarely (4), gamopetalous, twisted. Androecium—stamens 5, rarely 4, epipetalous, alternating with the petals, included within the corolla-tube; anthers usually connate around the stigma and apparently adnate to it. Disc present, ring-like [illegible] with marginal placentation, and when syncarpous the ovary may be 1-celled with parietal placentation, or 2-celled with axile placentation; ovules 2-∞ in each. Fruit a pair of follicles or berries or drupes. Seeds often with a crown of long silky hairs; mostly with endosperm. *Floral formula*—$\oplus$ ⚥ $K_{(5)}\overline{C_5A_{(5)}}\underline{G}_{(2)\text{ or }2}$.

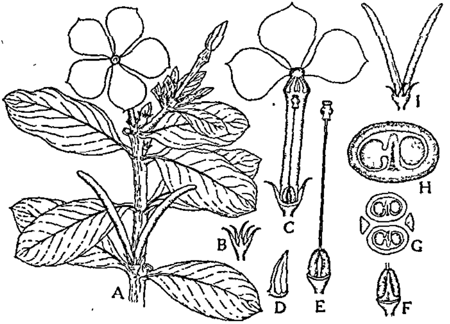


Apocynaceae. FIG. 38. Oleander (*Nerium indicum*). *A*, a whorl of leaves; *B*, a flower; *C*, a flower opened out; *D*, calyx; *E*, a petal; *F*, a stamen (connective with hairy appendage); and *G*, pistil.

Apocynaceae is related to *Asclepiadaceae* in general habit, bicollateral vascular bundles, latex tubes, and general floral and fruit characters. The two families, however, can be easily distinguished from each other by the characters of androecium and gynoecium.

Examples. Useful plants: medicinal: *Rauwolfia serpentina* (B. SARPAGANDHA; H. SARPGAND), *Holarrhena antidysenterica* (B. KURCHI;

H. KARCHI), *Wrightia tomentosa* (B. DUDH-KHOROI: H. DUDHI), yellow oleander (*Thevetia peruviana*)—seeds very poisonous, devil tree (*Alstonia scholaris*), etc.; **fruits:** *Carissa carandas* (B. KARANJA; H. KARONDA)—a thorny shrub, and *Willughbeia* (B. LATA-AM); **ornamental:** herb—periwinkle (*Vinca rosea*); shrubs—oleander (*Nerium indicum*), *Ervatamia divaricata* (B. TAGAR; H. CHANDNI), pagoda

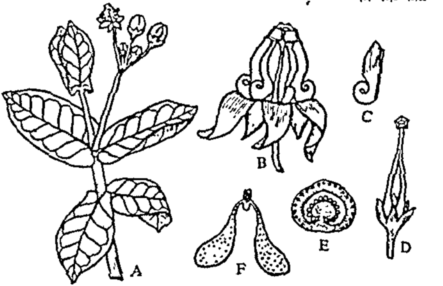


or life tree (*Plumeria rubra*); climbers—*Aganosma dichotoma* (B. MALATI; H. MALTI), *Vallaris solanacea* (B. HAPARMALI; H. RAMSAR), *Beaumontia grandiflora*, *Allamanda* and *Roupellia*; tree—*Cerbera odollam*; **other common plants:** *Ichnocarpus frutescens* (B. & H. DUDHI-LATA)—a climber, and *Rauwolfia canescens*—a shrub.

FAMILY 28 *Asclepiadaceae (1,800 sp.—213 sp. in India)*

Habit—herbs, shrubs or twiners; with latex. **Leaves** opposite. **Flowers** regular, bisexual and hypogynous. **Calyx**—sepals (5), slightly connate at the base, odd sepal posterior. **Corolla**—petals (5), connate; aestivation commonly twisted, sometimes valvate. **Androecium**—stamens (5), connate in a hollow tube, with horn-like appendages known as the staminal corona, epipetalous; anthers coherent laterally and united with the style and the stigma forming a gynostegium; pollen cohering into two pollen masses known as the pollinia (sing. pollinium), one lying in each lateral anther-lobe. **Gynoecium**—carpels two, free, superior; styles 2, free but united above forming a large dilated 5-angled stigma; stigma with five receptive surfaces lying on the underside or the edge of it; ovaries 2,

free or united at the base only, each unilocular with many ovules in it; placentation marginal on a large intruding ventral placenta. Fruit a pair of follicles, or by abortion only one. Seeds many, hairy. *Floral formula*—$\odot \text{⚥} K_{(5)} \overline{C_{(5)} [A_{(5)}} \underline{G}_2]$.



... a branch; ... er side); *D*, ... ary showing ... (see also FIG. I/115).

At each angle of the stigma there is a groove which secretes a sticky body called the corpusculum. The sticky secretion extends on either side into a connecting thread (retinaculum) to which each pollinium becomes attached.

Examples. Useful plants: medicinal: Indian sarsaparilla (*Hemidesmus indicus*; B. & H. ANANTAMUL), *Tylophora asthmatica*, madar (*Calotropis gigantea* and *C. procera*)—also floss from seeds used for stuffing pillows and cushions; ornamental: *Stephanotis*—a climber with white fragrant flowers, *Cryptostegia grandiflora*—a woody climber with large white flowers, *Pergularia*—an extensive twiner with small fragrant flowers; other common plants: milk-weed or blood-flower (*Asclepias curassavica*)—an erect herb with orange-red flowers, *Sarcostemma* (B. SOM-LATA)—a shrub, *Hoya*—a thick-leaved epiphytic climber, *Dischidia nummularia*—a slender but extensive epiphytic climber, *D. rafflesiana* (see FIG. I/67)—an epiphytic climber, *Daemia extensa*—a foetid climbing undershrub, *Dregea volubilis*—a woody twiner with small greenish flowers, *Sarcolobus globosus* (B. BAOLI-LATA)—a large climber.

FIG. 41. *Left*, a pair of follicles of madar; *right*, a hairy seed of the same.

FAMILY 29 *Boraginaceae (1,800 sp.—141 sp. in India)*

Habit—herbs (annual or perennial), shrubs or trees, often covered with stiff hairs. **Leaves** simple, alternate, entire. **Inflorescence** a scorpioid cyme, sometimes coiled. **Flowers** regular, bisexual, hypogynous. **Calyx** — sepals 5, free or united below into a tube, usually persistent, commonly imbricate. **Corolla**—petals (5), gamopetalous, tubular or funnel-shaped, with scales at the throat, lobes imbricate. **Androecium**—stamens 5, epipetalous, alternating with the corolla-lobes, commonly inserted at the mouth of the corolla-tube. **Gynoecium**—carpels (2), syncarpous, on an annular disc; ovary superior, 2-locular with 2 ovules in each, or commonly 4-locular with 1 ovule in each; style gynobasic, rarely terminal. **Fruit** a group of 4 nutlets. *Floral formula*—⊕ ⚥ $K_5\overline{C_{(5)}A_5}\underline{G}_{(2)}$

Examples. Herbs (weeds): heliotrope (*Heliotropium indicum*), *H. strigosum*, hound's tongue (*Cynoglossum lanceolatum*), *Trichodesma indicum*, etc.; shrub: *Tournefortia*; trees: *Cordia sebestana*—planted in gardens, *Ehretia*, etc.

FAMILY 30 *Convolvulaceae (1,100 sp.—157 sp in India)*

Habit—mostly twiners, often with latex and bicollateral vascular bundles or internal phloem. **Leaves** simple, alternate and exstipulate. **Inflorescence** cymose. **Flowers** regular, bisexual, hypogynous, often large and showy. **Sepals** 5, usually free, odd one posterior, imbricate and persistent. **Petals** (5), united, funnel-shaped, twisted in bud,

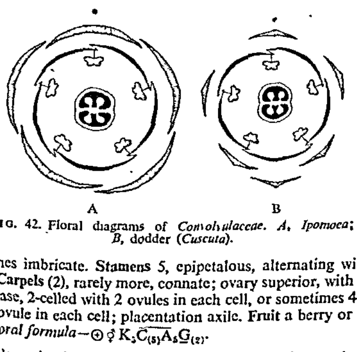
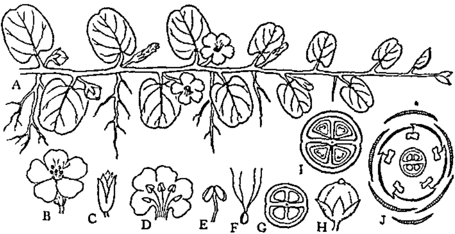


FIG. 42. Floral diagrams of *Convolvulaceae*. *A*, *Ipomoea*; *B*, dodder (*Cuscuta*).

sometimes imbricate. **Stamens** 5, epipetalous, alternating with the petals. **Carpels** (2), rarely more, connate; ovary superior, with a disk at the base, 2-celled with 2 ovules in each cell, or sometimes 4-celled with 1 ovule in each cell; placentation axile. **Fruit** a berry or a capsule. *Floral formula*—⊕ ⚥ $K_5\overline{C_{(5)}A_5}\underline{G}_{(2)}$.

Convolvulaceae is related to *Solanaceae* by its persistent calyx, regular gamopetalous corolla, 5 epipetalous stamens, often false septum in the ovary, bicollateral vascular bundles, etc ; but it is distinguished from it by definite number

(1 or 2) of ovules in each chamber of the ovary, micropyle pointing downwards, median carpels, etc.



Convolvulaceae. FIG. 43.
B, a flower; *C*, calyx; *D*,
E, a stamen; *F*, gynoecium
times 2 or 3); *H*, a fruit; *I*,

Examples. *Ipomoea* (400 sp.), *Convolvulus* (200 sp.), *Cuscuta* (100 sp.) are the largest genera of the family. **Useful plants**: **vegetables**: sweet potato (*Batatas edulis*=*Ipomoea batatas*) and water bindweed (*Ipomoea reptans*); **medicinal**: *Ipomoea paniculata* (B. & H. BHUI-KUMRA), *I. hederacea* and Indian jalap (*Operculina turpethum*); **ornamental**: morning glory (*I. purpurea*), railway creeper (*I. palmata*), moon flower (*I. grandiflora*), *I.*
caprae—a sand- and mud-bindi
clit pinnata (B. KUNJALATA; H
climber (*Argyreia speciosa*; B. SAMUDRA-SOK; H. SAMANDER-PHEN); **other common plants**: dodder (*Cuscuta reflexa*—see FIG. I/21), bridal creeper (*Porana paniculata*) and *Evolvulus alsinoides* (FIG. 43)—a very common prostrate weed with white flowers in grassy places.

FAMILY 31 *Solanaceae* (*2,000 sp.—58 sp. in India*)

Habit—herbs and shrubs; bicollateral bundles or internal phloem often present. Leaves simple, sometimes pinnate, as in tomato, alternate. **Flowers** regular, bisexual, hypogynous. **Calyx**—sepals (5), united, persistent. **Corolla**—petals (5), united, usually funnel- or cup-shaped, 5-lobed, lobes valvate or twisted in bud. **Androecium**—stamens 5, epipetalous, alternating with the corolla-lobes; anthers apparently connate. **Gynoecium**—carpels (2), syncarpous; ovary superior; 2-celled or sometimes 4-celled owing to the development of a false septum, as in tomato and thorn-apple, with many ovules in

each; placentation axile. **Fruit** a berry or capsule with many seeds. *Floral formula*—$\oplus$ ⚥ $K_{(5)}\overline{C_{(5)}A_5}\underline{G}_{(2)}$.

Solanaceae is related to *Convolvulaceae* (see p. 613). It is closely related to *Scrophulariaceae* through *Brunfelsia* and some others which have a zygomorphic corolla and 4 or 2 stamens. *Solanaceae* is, however, generally distinguished from the latter family by having regular corolla, twisted aestivation, five stamens, obliquely placed carpels, often bicollateral vascular bundles in the stem, etc.

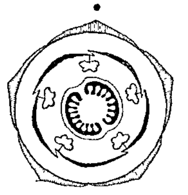
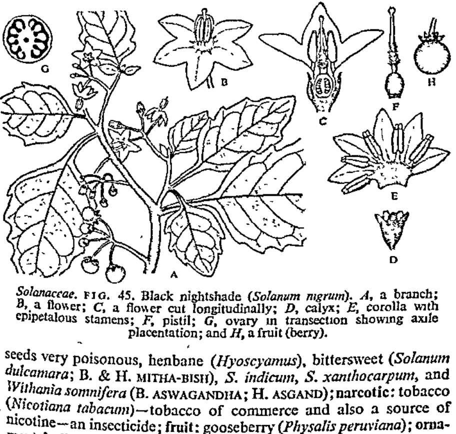


FIG. 44. Floral diagram of *Solanaceae*.

Examples. *Solanum* with 1,200 sp. is the largest genus of the family. **Useful plants: vegetables:** potato (*Solanum tuberosum*), brinjal (*S. melongena*), chilli or red pepper (*Capsicum frutescens*) and tomato (*Lycopersicum esculentum*); **medicinal**: deadly nightshade (*Atropa belladonna*), thorn-apple (*Datura fastuosa*)—



Solanaceae. FIG. 45. Black nightshade (*Solanum nigrum*). *A*, a branch; *B*, a flower; *C*, a flower cut longitudinally; *D*, calyx; *E*, corolla with epipetalous stamens; *F*, pistil; *G*, ovary in transection showing axile placentation; and *H*, a fruit (berry).

seeds very poisonous, henbane (*Hyoscyamus*), bittersweet (*Solanum dulcamara*; B. & H. MITHA-BISH), *S. indicum*, *S. xanthocarpum*, and *Withania somnifera* (B. ASWAGANDHA; H. ASGAND); **narcotic:** tobacco (*Nicotiana tabacum*)—tobacco of commerce and also a source of nicotine—an insecticide; **fruit:** gooseberry (*Physalis peruviana*); **ornamental:** *Petunia*, queen of the night (*Cestrum nocturnum*; B. HAS-NA

HANA; H. RAT-KI-RANI), etc.; **other common plants**: black nightshade (*Solanum nigrum*; FIG. 45), wild gooseberry (*Physalis minima*) and wild tobacco (*Nicotiana plumbaginifolia*).

FAMILY 32 *Scrophulariaceae (2,600 sp.—258 sp. in India)*

Habit—mostly herbs and undershrubs. **Leaves** simple, alternate, opposite or whorled, exstipulate, sometimes showing heterophylly. **Inflorescence** commonly racemose (raceme or spike), sometimes cymose (dichasium), axillary or terminal; in some species flowers solitary. **Flowers** zygomorphic, 2-lipped, sometimes personate, but often showing a great diversity in form, bisexual, hypogynous; bracts and bracteoles generally present. **Calyx**—sepals (5), gamosepalous, 5-lobed, often imbricate. **Corolla**—petals (5), gamopetalous, often 2-lipped, sometimes spurred or saccate, medianly zygomorphic, very

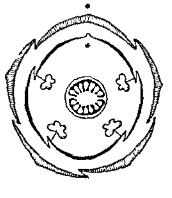
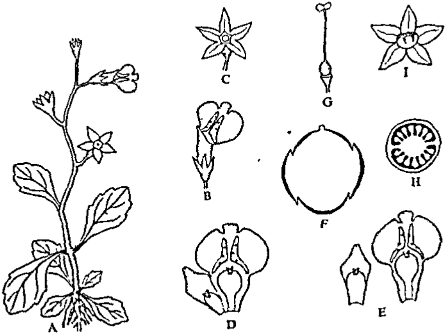


FIG. 46. Floral diagram of *Scrophulariaceae*.



Scrophulari[illegible] herb. *B*, a [illegible] corolla spl[illegible] pairs; *E*, co[illegible] stamens arching over; *F*, aestivation of corolla—imbricate; *H*, ovary in transection showing axile placentation; and *I*, fruit—capsule (dehiscing) with persistent calyx.

rarely regular as in *Scoparia*, imbricate. **Androecium**—stamens 4, didynamous, sometimes 2, arching over in pairs, posterior stamen absent or a staminode; anthers divaricate. **Gynoecium**—carpels (2), syncarpous; ovary superior, bilocular, antero-posterior (and not oblique as in *Solanaceae*); placentation axile; stigma simple or bilobed; ovules usually numerous, sometimes few; disc ring-like around the base of the ovary, sometimes unilateral. **Fruit**—commonly a capsule, sometimes a berry. Seeds usually numerous, minute, endospermic. *Floral formula*— ·|· ⚥ $K_{(5)}\overline{C_{(5)}A_4}$ or $_2\underline{G}_{(2)}$.

Scrophulariaceae is closely related to *Solanaceae* but is distinguished from it by its simple collateral bundles in the stem, zygomorphic corolla, imbricate aestivation, stamens 4 (didynamous) or 2, median position of the ovary, etc It is distinguished from *Labiatae* and *Verbenaceae* by its inflorescence and fruit. It is also related to *Acanthaceae* (see p. 618).

Examples. Useful plants: medicinal: foxglove (*Digitalis purpurea*), *Herpestis monnieria* (B. BRAHMI-SAK); **ornamental:** snapdragon

FAMILY 33 *Bignoniaceae (800 sp.—25 sp. in India)*

pnic, hypogynous; bracts and bracteoles present. **Calyx**—sepals (5), gamosepalous. **Corolla**—petals (5), gamopetalous, usually obliquely bell- or funnel-shaped; aestivation imbricate. **Androecium**—stamens 4, epipetalous, didynamous; anthers 2-lobed, lobes divaricate. **Gynoecium**—carpels (2), syncarpous; ovary superior, usually 2-locular, with many ovules in each; placentation axile. **Fruit** a 2-valved capsule, sometimes a berry. Seed usually flattened, with membranous wing. *Floral formula*— ·|· ⚥ $K_{(5)}\overline{C_{(5)}A_4}\underline{G}_{(2)}$.

Examples. *Bignonia* (150 sp.)—usually tendril-climbers, often with showy flowers, e.g. *B. venusta*, *B. unguis-cati*, etc., *Tecoma grandiflora* —a common garden climber, *T. stans*—a garden shrub, Indian cork tree (*Millingtonia hortensis*) —a tall robust tree with sweet-scented flowers, *Stereospermum chelonoides*—a large tree, *Oroxylon indicum* (see FIG. I/167A) —a small tree, *Spathodea campanulata*—a medium-sized tree with large red flowers, *Jacaranda acutifolius*—planted as a roadside tree, with purplish flowers in panicles, calabash (*Crescentia cujete*)—fruit large, gourd-like, etc.

FAMILY 34 *Acanthaceae (2,000 sp.—400 sp. in India)*

Habit—herbs, shrubs and a few climbers; cystoliths often present in

stem and leaf. Leaves opposite, exstipulate. **Inflorescence** a spike or a cyme or sometimes a raceme, flowers in some species in axillary clusters, rarely solitary. **Flowers** zygomorphic, often bilabiate, bisexual and hypogynous, often with conspicuous bracts and bracteoles

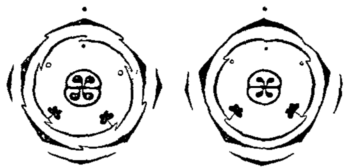


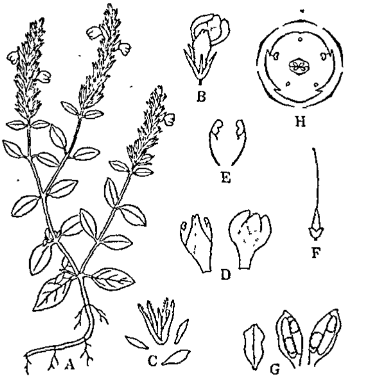
FIG 48 Floral diagrams (two types) of *Acanthaceae*.

which are sometimes spiny. **Calyx**—sepals (5), rarely (4), united. **Corolla**—petals (5), connate in a two-lipped or oblique corolla, twisted or imbricate in bud. **Androecium**—stamens 2 or 4, if 4 didynamous, epipetalous. **Gynoecium**—carpels (2), syncarpous; ovary 2-celled, superior, with 2 to many ovules in each cell; stigmas 2; placentation axile. **Fruit** a 2-valved capsule (FIG. 49*G*). **Seeds** are in most cases supported on curved hooks (jaculators); these press the fruit from inside, which bursts with a sudden jerk and scatters the seeds (see FIG. I/175). *Floral formula*—$\cdot|\cdot$ ⚥ $K_{(5)}\overline{C_{(5)}A_{2\text{ or }4}}\underline{G}_{(2)}$.

Acanthaceae is related to *Scrophulariaceae* but is distinguished from it by the presence of copious bracts and bracteoles, often unequal posterior sepal, loculicidal capsule dehiscing to the very base, seeds often with jaculators, absence of endosperm, frequent presence of cystolith, etc. It is also related to *Labiatae* (see p. 621), and to *Verbenaceae* (see p. 620).

Examples. Useful plants: medicinal: *Andrographis paniculata* (B. KALMEGH; H. MAHATITA), and *Adhatoda vasica* (B. BASAK; H. ADALSA); **ornamental:** *Barleria prionitis* (B. KANTA-JHANTI; H. VAJRA-DANTI)—spinous, flowers yellow, *B. cristata* (B. JHANTI)—flowers white or rose-coloured, *B. strigosa*—flowers blue, *Meyenia erecta*—a pretty shrub with deep blue flowers, *Crossandra*—an undershrub with orange-coloured flowers, *Strobilanthes*, *Eranthemum* (=*Daedalacanthus*) *nervosus*—flowers bright blue, etc.; **other common plants:** herbs—*Acanthus ilicifolius* (B. HARGOZA; H. HARKUCHKANTA), *Cardenthera triflora*—showing heterophylly (see FIG. I/76A), *Hygrophila spinosa* (B. KULEKHARA; H. GOKHULA-KANTA), *H. polysperma*—a common weed, *Ruellia tuberosa* (see FIG. I/175), *R. prostrata*, *Phaylopsis parviflora*, *Rungia parviflora*, *Dicliptera roxburghiana*, *Justicia simplex* (FIG. 49) and *Ecbolium linneanum* (B. NIL-KANTHA); climbers—*Thunbergia alata* and *T. grandiflora* (B. NIL-LATA);

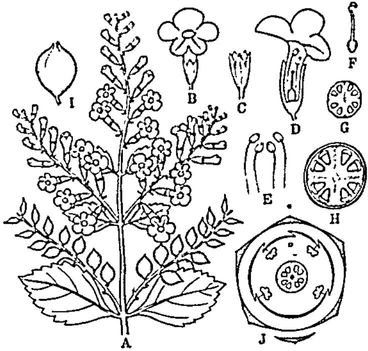
shrubs—*Justicia gendarussa* (B. JAGAT-MADAN) and several species of *Strobilanthes*.



FAMILY 35 *Verbenaceae (800 sp.—107 sp. in India)*

Habit—herbs, shrubs, trees or climbers, sometimes prickly, some xerophytic in habit, commonly strong-smelling; stem sometimes 4-angled. **Leaves** simple, opposite or whorled, sometimes pinnately or palmately compound. **Inflorescence** a raceme, panicle or spike (long or condensed) or a dichasial cyme. **Flowers** bisexual, medianly zygomorphic, hypogynous, pentamerous; bracts sometimes in the form of an involucre, as in *Lantana*. **Calyx**—sepals usually (5), rarely (4) or more, gamosepalous, persistent. **Corolla**—petals usually (5), gamopetalous, at first 2-lipped and later 5-lobed, tube long or short and limb oblique, aestivation imbricate. **Androecium**—stamens 4, didynamous, epipetalous, rarely 2, or 5 as in teak, inserted or exserted, alternating with corolla-lobes. **Gynoecium**—carpels commonly (2), rarely (4) as in *Duranta*, syncarpous; ovary superior, entire or lobed, 2-locular with 1 or 2 ovules in each or 4-locular with 1 ovule in each (8-locular in *Duranta*; FIG. 5CG); style terminal. **Fruit** a drupe

(consisting of 2 or 4 pyrenes), rarely a capsule. Seed exalbuminous. *Floral formula*—$\cdot|\cdot$ ⚥ $K_{(5)}\overline{C_{(5)}A_4}\,\underline{G}_{(2)}$.



Verbenaceae. FIG. 50. *Duranta plumieri. A,* a branch with inflorescence; *B,* a flower; *C,* calyx; *D,* a flower split lengthwise; *E,* stamens (didynamous); *F,* gynoecium ... 1 ovule); *H,* ... each 2-chamb... envelope is the fleshy persistent calyx), and *J,* ...

Verbenaceae is closely related to *Labiatae* both showing zygomorphy in the corolla, often extending to calyx in the latter. It is, however, distinguished from *Labiatae* by the following characters: in the former the inflorescence variously formed; ovary 2-locular with 1 or 2 ovules in each or *later* divided into 4 loculi with 1 ovule in each; style terminal; fruit usually drupaceous consisting of 2 or 4 pyrenes; whereas in the latter inflorescence a verticillaster or a cyme; 2-locular ovary *early* divided into 4 loculi with 1 ovule in each; style gynobasic, fruit consisting of 4 one-seeded nutlets. *Verbenaceae* is distinguished from *Acanthaceae*, another related family, by having 4-chambered ovary with 1 ovule in each or 2-chambered ovary with 1 or 2 ovules in each. The spike of *Acanthaceae* with often conspicuous bracts and bracteoles is another distinguishing feature. The fruit character also often distinguishes the two families.

Examples. Teak (*Tectona grandis*)—a very valuable timber tree, *Gmelina arborea* (B. GAMHAR)—a timber tree, *Duranta plumieri* (FIG. 50)—commonly grown as a hedge plant, *Lantana aculeata* (=*L. camara*)—a strong-smelling straggling shrub, *Clerodendron* (150 sp.), e.g. *C. infortunatum* (B. & H. BHANT), *C. siphonanthus*, *C. inerme*,

C. thompsonae (an elegant garden climber with white calyx and red corolla), etc., lady's umbrella (*Holmskioldia sanguinea*)—a shrub bearing beautiful scarlet flowers (common in the low hills of Assam), *Lippia* (120 sp.), e.g. *L. nodiflora*—a prostrate herb in wet places, *L. geminata*—a scandent shrub on the banks of tanks and canals, *Verbena* (100 sp.), e.g. *V. officinalis*—a small erect weed, *Avicennia*—a mangrove plant, *Premna*—shrub or tree common in the hills, *Vitex negundo* (B. NISHINDA)—a shrub, *V. trifolia*—a tree, *Callicarpa*—a shrub, etc.

FAMILY 36 *Labiatae (3,000 sp.—391 sp. in India)*

Habit—herbs and undershrubs with square stem. Leaves simple, opposite or whorled, exstipulate, with oil-glands. Flowers zygomorphic, bilabiate, hypogynous and bisexual. **Inflorescence** verticillaster (see p. 65); sometimes reduced to true cyme, as in sacred basil (*Ocimum*; B. & H. TULSI). **Calyx**—sepals (5), gamosepalous, unequally 5-lobed or 2-lipped, persistent. **Corolla**—petals (5), gamopetalous, bilabiate, i.e. 2-lipped; aestivation imbricate. **Androecium**—stamens 4, didynamous, sometimes only 2, as in sage (*Salvia*; see FIG. I/136), epipetalous. **Gynoecium**—carpels (2), syncarpous; disc prominent; ovary 4-lobed and 4-celled, with one ovule in each cell, ascending from the base of the ovary; style gynobasic (FIG. 52 *E & F*), i.e. develops from the depressed centre of the lobed ovary; stigma bifid. **Fruit** a group of four nutlets, each with one seed. *Floral formula*—$\cdot|\cdot$ ⚥ $K_{(5)} \overline{C_{(5)} A_4} \underline{G}_{(2)}$.

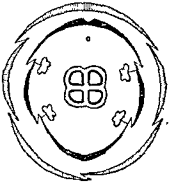


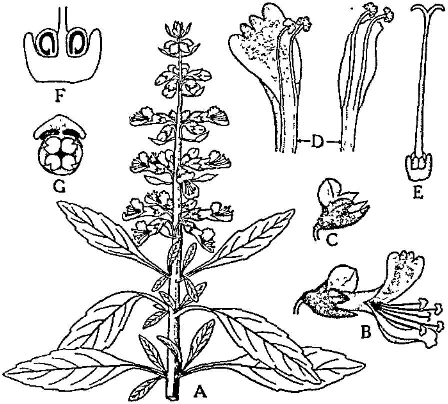
FIG. 51. Floral diagram of *Labiatae*.

Labiatae is closely related to *Verbenaceae* (see p. 620). It may be related to *Boraginaceae* by its fruit character (4 nutlets) but is readily distinguished from it by its inflorescence. *Labiatae* is distinguished from *Acanthaceae* and *Scrophulariaceae* by its inflorescence, lobed ovary and fruit structure.

Labiatae abounds in volatile, aromatic oils which are used in perfumery and also as stimulants. Many of them possess a bitter astringent property.

Examples. Useful plants: medicinal: sacred basil (*Ocimum sanctum*; B. & H. TULSI), mint (*Mentha arvensis*; B. PUDINA; H. PODINA), peppermint (*M. piperita*)—yields peppermint oil from which menthol is obtained, thyme (*Thymus*)—yields thyme oil from which thymol is obtained, patchouli (*Pogostemon*)—yields patchouli oil, lavender

(*Lavandula*)—yields lavender oil, and rosemary (*Rosmarinus*)—yields oil of rosemary; **ornamental**: sage (*Salvia plebeja* and *S. coccinea*), country borage (*Coleus aromaticus*—see FIG. I/6) and marjoram



Labiata
cences;
corolla
style);

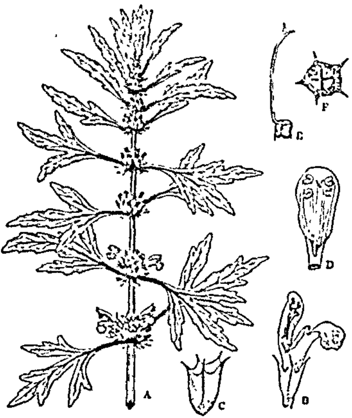
(*Origanum vulgare*)—cultivated for its scented leaves; **other common plants**: *Ocimum gratissimum* (B. & H. RAM-TULSI), basil (*O. basilicum*; B. & H. BABUI-TULSI), wild basil (*O. canum*; B. & H. BAN-TULSI), *Anisomeles indica*, *Leonurus sibiricus* (FIG. 53), *Leucas linifolia*, *L. aspera*, *Dysophylla*—marsh herbs, etc.

SUB-CLASS III MONOCHLAMYDEAE

FAMILY 37 *Nyctaginaceae* (*300 sp.—8 sp. in India*)

Habit—herbs, shrubs or climbers, showing anomalous secondary growth. **Leaves** simple, opposite, leaves of a pair often unequal, exstipulate. **Inflorescence** cymose. **Flowers** regular, bisexual or sometimes unisexual (as in *Pisonia*), hypogynous; bracts usually large and coloured, varying in number (3 petaloid bracts in *Bougainvillea* surrounding a group of 3 flowers; 5 sepal-like bracts in the form of an

involucre in *Mirabilis*; in *Boerhaavia* the involucral bracts are reduced to scales). Perianth leaves united, tubular or funnel-shaped, 5-lobed, petaloid, lower part of



the perianth is persistent in the fruit enveloping the latter like the pericarp (and known as the anthocarp). Androecium—stamens 5, alternating with the perianth-lobes but often very variable—1 or few or several (up to 30) by branching; filaments often unequal. Gynoecium—carpel 1; ovary superior, 1-locular, with a basal anatropous or campylotropous ovule; style long. Fruit an achene, 1-seeded and enclosed by the perianth-base. Seed endospermic, with mealy perisperm surrounded by a large, erect, folded or curved embryo. *Floral formula*—$\oplus$ ⚥ $P_{(5)}A_5G_1$.

FAMILY 38 *Amarantaceae (700 sp.—46 sp. in India)*

Habit—mostly herbs, sometimes climbing. Leaves simple, opposite or alternate, entire, exstipulate. Inflorescence an axillary cyme, a simple or branched spike, or

a raceme. Flowers small, regular, bisexual, rarely unisexual, pentamerous, often with scarious bracts and bracteoles. **Perianth**—members usually 4-5, free or united, membranous. **Androecium**—stamens 5 (often some reduced to staminodes), opposite the perianth leaves, free, or united to the perianth, or to one another into a membranous tube, sometimes petaloid outgrowths are present between the stamens; anthers 2- or 4-locular. **Gynoecium**—carpels (2-3), syncarpous; ovary superior, unilocular with commonly one campylotropous ovule (sometimes, as in cock's comb, several ovules are present). **Fruit** a utricle (1-seeded small fruit with loose perianth), or berry or nut or dehiscent (capsular). Seed endospermic. *Floral formula*—⊕ ⚥ $P_{4-5 \text{ or } (4-5)}A_5\underline{G}_{(2-3)}$.

Examples. Amaranth (*Amarantus*—60 sp.), e g. *A. spinosus*—a spinous weed, *A. tristis* (B. CHAMPA-NATE), *A. blitum* (=*A. oleracea*; B. SADA-NATE), *A. gangeticus* (B. LAL-SAK), *A. mangostanus* (B. NATE-SAK), *A. paniculatus* (B. DANTA), etc. —generally cultivated as vegetables, *A. viridis*, *A. tenuifolius*, *A. polygamus*, etc., —grow as common weeds, and some ornamental species of *Amarantus* bearing variegated leaves, chaff-flower (*Achyranthes aspera*)—a common weed, cock's comb (*Celosia* — 35 sp.), e g. *C. cristata* bearing red flowers, *C. argentea* bearing white flowers, *C. plumosa* bearing yellow flowers, etc , *Deeringia celosiodes* —a rambling climber bearing small globose scarlet fruits, *Cyathula tomentosa* —a densely tomentose undershrub, *Digera arvensis*—a common weed of fields and roadsides, *Alternanthera sessilis*—a very common prostrate weed, button flower or globe amaranth (*Gomphrena globosa*)—an ornamental garden plant, *Pupalia*—a climber with hooked fruits, *Aerua lanata* and *A. scandens*—weeds with pubescent branches, *Allmania nodiflora*—commonly grown as a garden border, etc.

FAMILY 39 *Chenopodiaceae (1,200 sp.—40 sp. in India)*

Habit—mostly herbs, rarely shrubs, often fleshy, sometimes covered with hairs; stem jointed in *Salicornia*; many are halophytic. **Leaves** —simple, usually alternate, rarely opposite, often fleshy, sometimes with hairs all over; in some species leaves remain undeveloped. **Inflorescence**—racemose with branches cymose. **Flowers** small, greenish, regular, bisexual or sometimes unisexual (as in *Atriplex*), hypogynous (except in *Beta*). **Perianth**—tepals 3-5, simple, sepaloid, free, imbricate. **Androecium**—stamens usually 5, opposite to the tepals, free or united at the base; disc sometimes present. **Gynoecium**—carpels usually (2-3), syncarpous; ovary superior (semi-inferior in *Beta*), unilocular, with one basal campylotropous ovule. **Fruit** a small nut, achene or berry. Seed often with mealy perisperm; embryo curved or rolled. *Floral formula*—⊕ ⚥ $P_{3-5}A_5\underline{G}_{(2-3)}$.

Examples. Vegetables: Indian spinach (*Basella rubra*), spinach (*Spinacia oleracea*), beet (*Beta vulgaris*)—the sugar-beet yielding about

phytes: saltwort (*Salsola foetida*)—a fleshy plant with spinous leaf-apex, *Salicornia brachiata*—a leafless succulent herb with jointed stems; yields barilla (an impure sodium carbonate), *Arthrocnemum indicum*—an undershrub growing with *Salicornia*, seablite (*Suaeda maritima* and *S. fruticosa*)—herbs with fleshy leaves, *Atriplex hortensis*—leaves succulent, etc.

FAMILY 40 *Polygonaceae (750 sp.—109 sp. in India)*

Habit—mostly herbs, sometimes climbing. Leaves simple, entire, alternate, opposite or whorled, with distinct ochreate stipules (a characteristic feature of the family). **Inflorescence** a raceme or spike, with lateral cymes. Flowers small, regular, bisexual, usually hypogynous, trimerous (rarely dimerous), cyclic or acyclic, sometimes medianly zygomorphic; several species are dimorphic. **Perianth**—members 3 or 6 (in two whorls), sometimes 5, generally uniform, often persistent. **Androecium**—stamens varying, commonly 3+3 in cyclic flowers, or 5–8 in acyclic flowers. **Gynoecium**—carpels (3) or sometimes (2), syncarpous; ovary superior, unilocular containing a single erect (orthotropous) ovule; styles 3 or 2. **Fruit** a small hard triangular nut. Seed albuminous, sometimes ruminated. *Floral formula*—$\oplus ⚥ P_{3+3}A_{3+3 \text{ or } 5-8}\underline{G}_{(3)}$.

Polygonaceae is related to *Urticaceae* by having unilocular ovary with a single orthotropous ovule According to Hutchinson it is derived from *Caryophyllaceae*.

Examples. *Polygonum* (275 sp. —88 sp. in India); some of the common species are *Polygonum plebejum*, *P. orientale*, *P. glabrum*, *P. hydropiper*, etc., sorrel (*Rumex vesicarius*)—cultivated for its sour leaves, *R. maritimus*—a common weed, buckwheat (*Fagopyrum esculentum*)—cultivated in the hills for grains used for making bread, rhubarb (*Rheum*)—cultivated as a vegetable, cocoloba (*Muehlenbeckia*) showing phylloclades (see FIG. I/38), Sandwich Island climber (*Antigonon leptopus* = *Corculum leptopus*; see FIG. 35B)—a common garden climber with pink or white flowers, etc.

FAMILY 41 *Loranthaceae (1,000 sp.—64 sp. in India)*

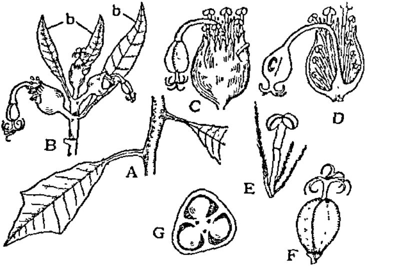
Habit—mostly semi-parasitic shrubs or undershrubs, developing sucking roots or haustoria. Leaves simple, commonly opposite, thick and leathery, exstipulate, sometimes reduced to scales. Inflorescence racemose, spicate or cymose, sometimes flowers in fascicles. Flowers unisexual or bisexual, regular or slightly zygomorphic, greenish or brightly coloured, epigynous. Perianth grows from the margin of the cup-shaped receptacle, in two whorls, sepaloid (in *Viscum*) or petaloid (in *Loranthus*); perianth leaves free or united into a tubular structure, usually 3- to 6-lobed; in *Loranthus* a small outgrowth (called calyculus) of the axis is present below the perianth; the calyculus is regarded by some as a calyx. Stamens opposite to perianth-segments and equal in number, united with the latter. Ovary inferior, sunken in the receptacle, 1-chambered; placenta not

differentiated from the ovules. Fruit a drupaceous or berry-like pseudocarp, with often a very sticky substance (viscin) round the seed. Seeds commonly 1, sometimes 2 or 3, albuminous; on germination the hypocotyl first forms a swollen sucker fixing the embryo to the branch of the host plant.

Examples. Two common genera are *Viscum* (60 sp.; with unisexual flowers) and *Loranthus* (500 sp.; with unisexual or bisexual flowers); mistletoe (*Viscum monoicum*) showing dichasial branching (see FIG. I/23); common species of *Loranthus* are *L. longiflorus*, *L. involucratus*, *L. globosus*, *L. scurrula*, *L. vestitus*, *L. coccinea*, etc.

FAMILY 42 *Euphorbiaceae* (*4,000 sp.—374 sp. in India*)

Habit—herbs, shrubs and trees, often with acrid milky juice. Leaves simple, usually alternate; stipules usually present. Inflorescence varying—racemose or cymose, or mixed, or a cyathium (see pp. 64-5), as in spurge (*Euphorbia*) and jew's slipper (*Pedilanthus*). Flowers small, bracteate, regular, hypogynous, always unisexual, monoecious or dioecious; rudiments of the other sex are sometimes present. Perianth in 1 or 2 whorls, sometimes absent, dissimilar in male and female flowers. *Floral formulae*—$\oplus$ ♂-♀ or ♂♀ $P_{0 \text{ or } 5} A_{1-\infty} G_0 (A_0 \underline{G}_{(3)}$.



Male Flowers: in spurges (*Euphorbia*) and jew's slipper (*Pedilanthus*) flowers are reduced to solitary stamens without any perianth (see pp. 64-5); in other cases stamens usually many or sometimes few; filaments either free or connate in 1 to many bundles.

Female Flowers: carpels (3), syncarpous; ovary 3-celled, 3-lobed, superior, with 1 or 2 ovules in each loculus, pendulous; styles 3, each bifid; stigmas 6. Fruit mostly a capsule or a regma

Euphorbiaceae is closely related to *Sterculiaceae* of Malvales by various degrees of union of stamens and the presence of pistillode and staminode in male and female flowers respectively, and sometimes also androphore and gynophore, and may have originated from a common ancestral stock of Malvales, but separated from the latter by reduction of floral parts. It is also very closely related to Geraniales by the structure of the gynoecium.

Examples. Some of the largest genera are *Euphorbia* (750 sp.), *Croton* (600 sp.), *Phyllanthus* (500 sp.), *Acalypha* (400 sp.), etc. Useful plants: castor (*Ricinus communis*; FIG. 55)—seeds yield castor oil, *Croton tiglium* (B. JAIPAL; H. JAMOLGOTA)—seeds yield croton oil, *Aleurites*—a few species are cultivated in India for TUNG oil, Indian walnut

(*A. moluccana*), *Baccaurea* (B. LATKAN; H. LUTKO)—aril pulpy and edible, emblic myrobalan (*Phyllanthus emblica*; B. AMLA; H. AMLIKA) —fruits edible, rich in vitamins, medicinal and also used for tanning, *P. acidus* (B. NOAR; H. CHALMERI)—fruits edible, sour but tasteful, tapioca (*Manihot utilissima*)—tuberous roots yield a valuable starchy food (tapioca), *M. glaziovii*—yields ceara rubber, *Hevea brasiliensis* —yields para rubber; ornamental: garden crotons (*Codiaeum variegatum*) with variegated leaves, poinsettia (*Euphorbia pulcherrima*; FIG. 54), *Bischofia* and *Bridelia* are timber trees, and child life tree (*Putranjiva roxburghii*; B. JIAPUT)—an evergreen shade tree; other common plants: spurges (*Euphorbia*), e.g. *E. antiquorum*, *E. neriifolia*, *E. nivulia*, *E. pilulifera*, *E. heterophylla*, *E. thymifolia*, *E. royleana*, etc., jew's slipper (*Pedilanthus tithymaloides*)—a garden plant, *Croton sparsiflorus*, *Phyllanthus niruri* (B. BHUI-AMLA) and *Acalypha indica* are common weeds, nettle (*Tragia involucrata*)—a twiner with stinging hairs, *Jatropha gossypifolia*, physic or purging nut (*J. curcas*), *Chrozophora plicata*—a common weed, *Breynia rhamnoides*—a shrub, and *Trewia nudiflora*—a tree.

FAMILY 43 *Ulmaceae (130 sp.—14 sp. in India)*

Habit—trees, with no latex. **Leaves** simple, alternate, distichous, often oblique; stipules present, caducous; cystoliths mostly present. **Inflorescence** cymose. **Flowers** small, regular, sometimes solitary, unisexual, monoecious, rarely bisexual, hypogynous. **Perianth**—tepals 4-5, free or united, sepaloid, imbricate. *Androecium*

Seed commonly exalbuminous; embryo straight or curved. *Floral formula*— $\oplus$ ♂-♀ P_{4-5} or $_{(4-5)}A_{4-5}G_0 \mid A_0\underline{G}_{(2)}$.

Examples. *Ulmus lancifolia*—a large deciduous tree, *Celtis australis*—a middle-sized deciduous tree, *Trema orientalis*—a fast-growing tree, the fibrous bark of which is beaten into a coarse mattress by the Garos.

FAMILY 44 *Moraceae (900 sp. —106 sp. in India)*

Habit—mostly trees, a few shrubs or herbs, with latex. **Leaves** simple, alternate, entire or lobed; stipules large, caducous; cystolith absent. **Inflorescence** cymose, usually in the form of raceme, spike, umbel or head; hypanthodium in *Ficus*. **Flowers** small, regular, unisexual, monoecious or dioecious, hypogynous. **Perianth**—tepals 4, free or united, often persistent in fruit. **Androecium**—stamens equal in number and opposite to the tepals, sometimes reduced to 1 or 2; filaments incurved or straight in bud; anther dehiscing. *Gynoecium* —carpels (2), syncarpous, 1-locular (one carpel usually abortive), superior to inferior; ovule solitary, campylotropous. Fruit a drupe,

nut or achene; the whole inflorescence sometimes develops into a multiple fruit (sorosis or syconus). Seed with or without endosperm; embryo curved.

Floral formula—$\oplus$ ♂-♀ or ♂ ♀ $P_{4 \text{ or } (4)} A_{4-1} G_0 \mid A_0 \underline{G}_{(2)} \text{ or } \overline{G}_{(2)}$.

Examples. Mulberry (*Morus indica*—with short spikes and *M. laevigata*—with long spikes)—fruits eaten; wood very valuable, particularly of the latter; silk worms are reared on mulberry, *Ficus* (800 sp.), e.g. fig (*F. glomerata*, *F. cunia*, *F. hispida*, etc.), *F. infectoria* (B. PAKUR), banyan (*F. bengalensis*), peepul or bo-tree (*F. religiosa*), India-rubber plant (*F. elastica*), Indian ivy (*F. pumila*; see FIG. I/16) etc., jack (*Artocarpus integrifolia*)—large summer fruit (sorosis), sweet and edible; wood used for furniture, monkey jack (*A. lakoocha*; B. & H. DEOPHAL)—fruit eaten; wood useful, chaplash (*A. chaplasha*; see FIG. I/76B)—wood valuable, *Streblus asper* (B. SHAORA)—a rigid evergreen tree, paper-mulberry (*Broussonetia papyrifera*) — wood very soft and light; bark used for making paper in Japan, *Cudrania javanensis*—a rambling shrub, *Conocephalus suaveolens*—a large evergreen woody climber, etc.

Distinguishing Characters

Urticaceae	*Moraceae*	*Ulmaceae*
Mostly herbs	trees or shrubs	trees
Latex absent; cystolith commonly present	latex present; cystolith absent	latex absent; cystolith mostly present
Flowers unisexual, hypogynous	unisexual, hypo- to epigynous	unisexual, rarely bisexual, hypogynous
Stamens 4-5, anther exploding, filaments incurved in bud	4, often reduced to 1 or 2, anther not exploding, filaments incurved or straight in bud	4-5, anther splitting longitudinally, filaments straight in bud
Carpel 1, style 1	(2), usually 1 aborted, styles 1 or 2	(2), styles 2
Ovary 1-locular, superior	1-locular, superior to inferior	2-locular or 1-locular, superior
Ovule orthotropous	campylotropous	anatropous or amphitropous
Endosperm oily	fleshy or absent	usually not present
Embryo straight	curved	straight or curved

FAMILY 45 *Urticaceae*[1] *(480 sp. —104 sp. in India)*

Habit—mostly herbs, sometimes shrubs, with no latex. Leaves simple, alternate or opposite with three basal nerves, with or without stinging hairs; cystoliths commonly present; stipules membranous. **Inflorescence** cymose (often condensed). **Flowers** small, regular, unisexual, monoecious or dioecious. **Perianth**—tepals usually 4, sometimes 5, free or connate, sepaloid. **Androecium**—stamens as many as the tepals and opposite to them; filaments incurved in bud; anthers exploding when mature. **Gynoecium**—carpel 1; ovary superior, 1-locular, with 1 basal orthotropous ovule. **Fruit** a small achene, nut or drupe. **Seed** usually with oily endosperm; embryo straight. *Floral formula*—⊕ ♂-♀ or ♂ ♀ $P_{4 \text{ or } (4)} A_{4 \text{ or } 5} G_0$ | $A_0 \underline{G}_1$.

Examples. With stinging hairs—nettles: *Urtica dioica* (also fibre-yielding), *Fleurya interrupta*, *Girardinia heterophylla* (also fibre-yielding), devil or fever nettle (*Laportea crenulata*), etc. Without stinging hairs: gunpowder plant (*Pilea microphylla*), rhea or ramie (*Boehmeria nivea*)—cultivated for best fibres (longest, toughest and silkiest), *Pouzolzia indica*—common on roadsides and waste places, *Elatostema*—a herb or undershrub common on hill-slopes.

FAMILY 46 *Cannabinaceae (3 sp —2 sp. in India)*

Aromatic herbs. Leaves palmi-nerved and palmately divided; stipules present and persistent; no latex. Flowers unisexual, dioecious, borne in cymes. *In male flowers* perianth leaves 5 and stamens 5 (opposite to perianth leaves), while *in female flowers* the perianth is entire and cup-shaped, and carpels (2); ovary 1-celled with 1 pendulous ovule Fruit a nut or achene. Seed albuminous or exalbuminous; embryo curved or spiral.

Examples. Only 2 genera—*Cannabis* (1 sp) and *Humulus* (2 sp). Hemp (*Cannabis sativa*)—yields valuable bast fibres and is the source of a narcotic resin in three forms: GANJA (resinous flowering shoots of cultivated female plants), CHARAS

FAMILY 47 *Casuarinaceae (40 sp.—1 sp. in India)*

Habit—trees with xerophytic habit; branches joined, and internodes furrowed. Leaves—alternating whorls of 4-12 minute scale-like leaves united at the base to form a sheath. Flowers—extremely simple, unisexual, monoecious, with a bract and two bracteoles. *Male flowers* borne in terminal catkin-like spike at the end of a branch, each consisting of a single stamen, two small perianth leaves, a bract and a pair of lateral bracteoles; flowers in whorls, and bracts in a sheath

[1] *Urticaceae* of Bentham and Hooker has been split up by Engler into three families—*Ulmaceae*, *Moraceae* and *Urticaceae* under the order Urticales. Hutchinson further splits up the order into four families—*Ulmaceae*, *Moraceae*, *Urticaceae* and *Cannabinaceae*; the last one has been isolated from *Moraceae*.

round each whorl. *Female flowers* borne in a more or less spherical head on a short lateral branch, each consisting of two carpels, a bract and 2 bracteoles which harden in the fruit; pistil syncarpous; ovary 1-celled by the suppression of the posterior cell; ovules generally 2, orthotropous, ascending, but 1 matures; stigmas 2, long and protruding. Pollination by wind; fertilization chalazogamic. Fruit a 1-seeded winged nut (the whole head, however, becomes woody and cone-like). Seed exalbuminous, winged.

Example. *Casuarina*, commonly called beef-wood or she-oak, is the only genus of the family (mainly Australian) *C. equisetifolia* is widely grown in India as a roadside or avenue tree.

Chapter 4 SELECTED FAMILIES OF MONOCOTYLEDONS

SUB-CLASS I PETALOIDEAE

FAMILY 1 *Liliaceae (2,600 sp.)*

Habit—herbs and climbers, rarely shrubs or trees, with fibrous roots, or bulb or corm or creeping rootstock. Leaves simple, radical or cauline or both. Flowers regular, bisexual and hypogynous, solitary or in spike, raceme or panicle; bracts small, scarious (thin and dry) or spathaceous. Perianth petaloid, usually 6 segments in two whorls, usually free (polyphyllous), sometimes united (gamophyllous). Androecium—stamens 6, in two whorls, rarely 3, hypogynous, free, or united with the perianth (epiphyllous) at the base. Gynoecium—carpels (3), syncarpous; ovary superior, 3-celled; ovules 2 or more in each loculus; placentation axile; stigmas usually 3. Fruit a berry or capsule. Seeds albuminous. *Floral formula*—$\oplus$ ⚥ $P_{3+3}A_{3+3}\underline{G}_{(3)}$ or $\overline{P_{(3+3)}A}_{3+3}\underline{G}_{(3)}$.

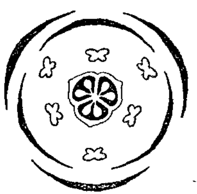
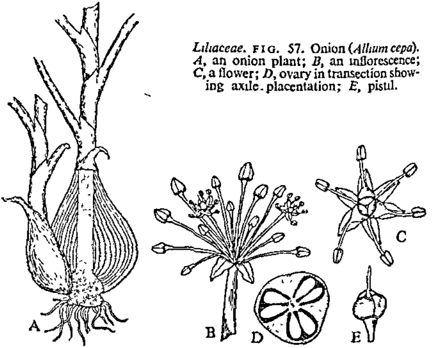


FIG. 56. Floral diagram of *Liliaceae*.

Examples. Useful plants—vegetables: *Allium* (325 sp.), e.g. onion (*A. cepa*), garlic (*A. sativum*)—also medicinal, shallot (*A. ascalonicum*), leek (*A. tuberosum*), etc.; medicinal: *Asparagus* (100 sp.), e.g. *A. racemosus*, *Smilax* (200 sp.), e.g. sarsaparilla (*S. macrophylla*; see

Liliaceae. FIG. 57. Onion (*Allium cepa*). *A*, an onion plant; *B*, an inflorescence; *C*, a flower; *D*, ovary in transection showing axile placentation; *E*, pistil.



glory lily (*Gloriosa superba*; see FIG. I/61*C*), day lily (*Hemerocallis*), dagger plant or Adam's needle (*Yucca gloriosa*; see FIG. I/78), dragon plant (*Dracaena*), *Sansevieria lourentii*—green foliage with yellow margin, *Scilla indica* propagating by leaf-tips, and *Asparagus plumosus*; **fibre-yielding**: *Phormium* yielding New Zealand flax, and bowstring hemp (*Sansevieria roxburghiana*)

FAMILY 2 *Amaryllidaceae* (*950 sp.*)

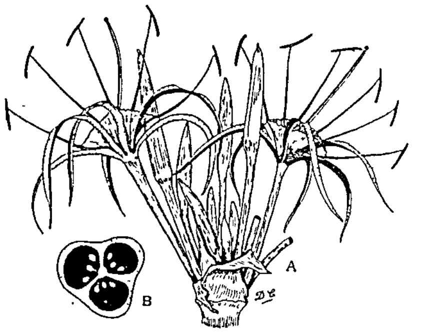
This has the same general characters as *Liliaceae*, but differs from the latter in its ovary being inferior. *Floral formula*—⊕ ⚥ $P_{3+3}A_{3+3}\overline{G}_{(3)}$ or $\overline{P_{(3+3)}}A_{3+3}\overline{G}_{(3)}$.

Examples. Easter lily (*Amaryllis*), eucharis lily (*Eucharis*), pin-cushion lily (*Haemanthus*), spider lily (*Pancratium*; FIG. 58), zephyr lily (*Zephyranthes*), tuberose (*Polyanthes tuberosa*), American aloe or century plant (*Agave americana*), *Curculigo orchioides* (B. TALMULI; H. MUSLIKAND), daffodil (*Narcissus*), *Crinum* (130 sp.), e g *C. asiaticum*, *C. latifolium*, etc.

FAMILY 3 *Commelinaceae* (*about 400 sp.*)

Habit—annual or perennial herbs, with jointed stem. Leaves simple, alternate, with sheathing base. Flowers more or less regular, commonly blue, sometimes

whitish or pinkish, bisexual, hypogynous, in monochasial cyme, enclosed in a distinct spathe. Perianth—6 segments in two series, distinguishable into the outer



Amaryllidaceae. FIG. 58. Spider lily (*Pancratium*). *A*, inflorescence; and *B*, ovary in transection showing axile placentation.

sepaloid calyx and the inner petaloid corolla, sepals and petals generally free. Androecium—stamens 6 in two whorls, either all perfect or some reduced to staminodes or absent; filaments often bearded with hairs. Gynoecium—carpels (3), syncarpous; ovary superior, 3-celled; placentation axile; ovules solitary or few, orthotropous. Fruit a dehiscent capsule or indehiscent. Seeds albuminous. *Floral formula*—⊕ ⚥ $K_3C_3A_{3+3}\underline{G}_{(3)}$.

Examples. *Commelina* with 115 sp., e.g *C. bengalensis* (see FIG. I/133), *C. salicifolia*, *C. obliqua*, *C. nudiflora*, etc., *Aneilema* with 80 sp., e.g *A. nudiflorum*, *A. spiratum*, etc., *Cyanotis axillaris*, *C. cristata*, *Floscopa scandens*, *Tradescantia* (=*Rheo*) *discolor*, etc.

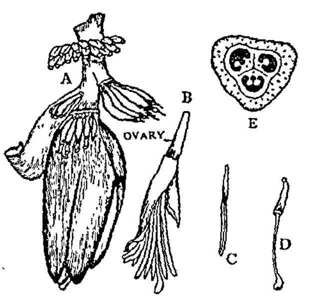
FAMILY 4 *Scitamineae*[1] (*1,180 sp.*)

Habit—herbs (rarely woody and tree-like, e.g. traveller's tree); underground stem usually in the form of a slender or stout rhizome; aerial stem distinct or 'false' made of sheathing leaf-bases, and the flowering stem or scape pushing out through the 'false' stem and ending

[1] *Scitamineae* of Bentham and Hooker has been raised by Engler to the rank of an order with four families—*Musaceae*, *Zingiberaceae*, *Cannaceae* and *Marantaceae*. Hutchinson has renamed the order Zingiberales with the above four families.

in an inflorescence. Inflorescence a raceme, spike or spadix with often large spathes, either terminal or axillary. Flowers zygomorphic, mostly bisexual and epigynous; bracts often spathaceous. Perianth of six segments in two whorls. Androecium—stamens varying (see sub-families). *Gynoecium—carpels* (3), *syncarpous; ovary* inferior and trilocular; placentation axile; ovules usually many. Fruit a berry or capsule Seeds with perisperm, sometimes with aril or with endosperm. This family has been divided into three sub-families, mainly depending on the number of stamens.

(1) *Musaceae* (150 sp.). Perianth petaloid in two series—one with 5 limbs united and another solitary and free. Stamens in 2 whorls, 5 perfect and the 6th one sterile or absent.
Floral formula— ·|· ⚥ $P_{(5)+1}A_{3+2}\overline{G}_{(3)}$.

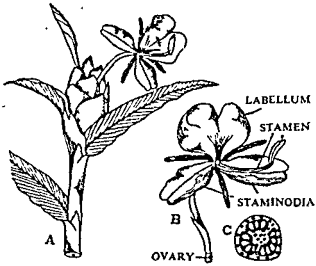


Musaceae.
FIG. 59.
Banana (*Musa paradisiaca*).
A, spadix;
B, a flower;
C, a stamen;
D, pistil; and
E, ovary in transection showing placentation (section taken from a wild variety).

Examples. *Musa* (80 sp.), e.g. banana (*M. paradisiaca*)—a dessert fruit, plantain (*M. sapientum*)—green fruit used as a vegetable, dwarf plantain of Assam (*M. sanguinea*)—fruit not edible, *M. superba* and *M. nepalensis*—ornamental, fruits not edible, *M. textilis* yielding commercial Manila hemp, and traveller's tree (*Ravenala madagascariensis*; B. PANTHAPADAP—see FIG. I/71).

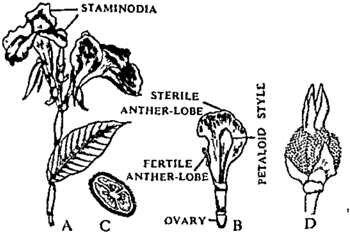
(2) *Zingiberaceae* (800 sp.). Perianth of 6 segments in 2 whorls, generally distinguishable into calyx and corolla. Stamens in 2 whorls—only 1 perfect and epipetalous (this is the posterior one of the inner whorl), the other 2 stamens of this whorl are united to form a 2-lipped labellum; the anterior stamen of the outer whorl is absent and the remaining 2 modified into petaloid staminodes or absent. Style slender, passing through the two anther-lobes.
Floral formula— ·|· ⚥ $K_{(3)}\widehat{C_3 A_1}\overline{G}_{(3)}$.

CHAMPA), *Kaempferia rotunda* (B. BHUI-CHAMPA), *Costus speciosus*,



Zingiberaceae. FIG. 60. Butterfly lily (*Hedychium coronarium*). *A*, a branch with inflorescence; *B*, a flower; and *C*, ovary in transection showing axile placentation.

Alpinia allughas (B. TARA), *A. galanga*—medicinal, *Globba bulbifera* (see FIG. III/58), cardamom (*Elettaria cardamomum*), *Amomum subulatum* (B. BARA-ELAICH), *A. aromaticum* (B. MORAN-HANCHI).



Cannaceae. FIG. 61. Indian shot (*Canna indica*). *A*, a branch; *B*, a flower (perianth and staminodia cut out); *C*, ovary in transection showing axile placentation; and *D*, a fruit.

(3) *Cannaceae* (60 sp.). **Perianth** in 2 whorls of 3 members each —the outer 3 (sepals) free and the inner 3 (petals) united. Stamens in 2 whorls—only 1 anther-lobe of 1 stamen (the posterior one of the inner whorl) fertile, the other anther-lobe together with the filament becoming petaloid; one stamen is suppressed and the other

stamens modified into petaloid staminodes, one of which forms the labellum covering the style. All petaloid staminodes together with the petaloid anther-lobe are united below with the corolla into a cylindrical tube. Style petaloid and flattened.
Floral formula— $\cdot|\cdot$ ⚥ $K_3C_{(3)}A_{\frac{1}{2}}\bar{G}_{(3)}$.

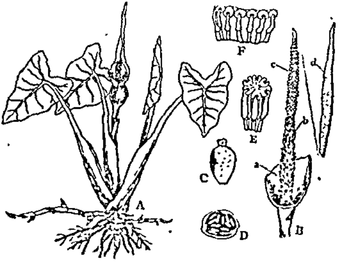
Examples. Only genus is *Canna* with about 60 sp. in tropical America. Indian shot (*Canna indica*) with many varieties and hybrids is grown widely in Indian gardens.

(4) *Marantaceae* (300 sp.). Floral characters like those of *Cannaceae*. It is distinguished, however, from allied families by the presence of a joint or swollen pulvinus at the junction of the petiole and the leaf-blade. It is chiefly a tropical American family.
Floral formula— $\cdot|\cdot$ ⚥ $P_{3+3}A_{\frac{1}{2}}\bar{G}_{(3)}$.

Examples. *Maranta* (30 sp.), e.g. arrowroot (*Maranta arundinacea*), some ornamental species of *Maranta*, e.g. *M. sanderiana*, *M. zebrina*, etc., *Clinogyne dichotoma* (B. SITALPATI), and *Phrynium*—ornamental.

FAMILY 5 *Araceae* (*1,900 sp.*)

Habit—herbs, or occasionally climbing shrubs with two kinds of aerial roots—clinging roots fixing the plant to its support and hanging roots ultimately growing down into the soil, with an acrid juice or latex which is in some cases poisonous. Stem in the form of rhizome or corm. Plants of this family grow in moist, shady places. Leaves are alternate, radical, simple or compound; in climbing species cauline leaves distinctly alternate, often broad, long-petioled and palmately veined (reticulate). Inflorescence in the form of spadix subtended by a large,



drium opened out.

often brightly coloured spathe; usually monoecious with female flowers at the base, higher up some neuter flowers in some species and above them a number of closely-packed male flowers; the axis of the spadix is prolonged into a sterile appendix. Flowers sessile, small, naked, unisexual (monoecious or dioecious) or sometimes bisexual. Perianth absent or of 6 or 4 scales. Androecium—stamens (6) in 1 or 2 whorls, or reduced in number, even to 1, filaments very short, often united at the base or into a *synandrium*; anthers 2-celled, often dehiscing by terminal pore. Gynoecium—carpels (1-3), connate; ovary 1- to 3-celled, superior; each cell with 1 or more ovules; placentation often parietal. Fruit a berry. Seed with or without endosperm. Flowers are protogynous and pollination is mainly effected by insects. Appendix in many species with strong, offensive smell. *Floral formula*—♂-♀ or ♂ ♀ $P_0A_{(6-1)}G_0 \mid A_0\underline{G}_{(1-3)}$

Examples. Taro (*Colocasia esculenta*; FIG. 62), *Alocasia indica* (B. MANKACHU; H. MANKANDA), *Typhonium trilobatum* (B. GHETKACHU—see FIG. I/82), trumpet- or arum-lily (*Richardia*), *Amorphophallus campanulatus* (B. OL; H. KANDA—see FIG. I/134), Portland arrowroot (*Arum maculatum*), snake plant (*Arisaema*—see FIG. I/80), sweet flag (*Acorus calamus*; B. BOCH; H. WACH), water lettuce (*Pistia* [illegible], *Pothos scandens*—a climber [illegible] *Monstera* and *Philodendron* [illegible] 00 sp.)—ornamental herbs.

FAMILY 6 *Palmaceae (1,500 sp.)*

Habit—shrubs or trees, sometimes climbing, e.g. cane (*Calamus*). [illegible], e.g. *Hyphaene*. [illegible] from the base of [illegible] bud, sometimes very large (in some species 15 m. long and 2.5 m. wide); they are of two types—palmately cut or divided (fan palms) or pinnately cut or divided (feather palms); petiole often with sheathing base. Flowers sessile, small and inconspicuous but produced in immense numbers presenting an imposing appearance (date-palm bears about 12,000 male flowers and *Metroxylon* about 624,000 flowers), regular, hypogynous, unisexual (rarely bisexual), in simple or compound spadix enclosed in one or more sheathing spathes; male and female flowers in the same inflorescence or in two, either monoecious or dioecious. Perianth in two series, 3+3, the outer being often smaller, imbricate and persistent in the female flower. Androecium—stamens usually in two series, 3+3; filaments free or connate; anthers versatile, 2-celled. Rudiment of the pistil sometimes present in the male flower. Gynoecium—carpels (3) or 3, syncarpous or apocarpous; ovary superior, unilocular or trilocular, with 1 or 3 ovules. Fruit a drupe, berry or nut. Seed albuminous. Pollination by wind; pollen produced in huge quantities. Some palms are pollinated by insects also. Flowers protandrous, and hence self-pollination is prevented.
Floral formula—⊕ ♂-♀ or ♂ ♀ $P_{3+3}A_{3+3}G_0 \mid A_0\underline{G}_{(3)\text{ or }3}$.

Economically this is one of the most important families as many useful products

are obtained from several species of it. Many palms such as palmyra-palm, toddy-palm, date-palm coconut-palm, etc., are tapped for toddy (fermented country liquor) or for sweet juice from which jaggery or sugar is made. Coconut-palm, date-palm, palmyra-palm, etc., yield edible fruits. Coir fibres of coconut-palm are used for making mats, mattresses and brushes, and also for stuffing cushions. Leaves of many palms are woven into mats, hats and baskets and also used for thatching Some palms yield oil, e g coconut-palm, oil-palm, etc. Sago-palms (*Metroxylon* and *Caryota*) yield sago, which is obtained by crushing the pith. Betel-nut is used for masticating with betel leaf. Endosperm of vegetable ivory-palm is very hard and made into billiard balls. Cane is used for making chairs, sofas, tables, and baskets and for a variety of other purposes. Many palms are ornamental, e g. fan palms *Livistonia, Licuala, Sabal, Prichardia grandis*—a very beautiful palm, and feather palms· cabbage-palm (*Areca oleracea*), sugar-palm (*Arenga saccharifera*), bottle-palm (*Oreodoxa regia*), *Pinanga*, dwarf cane (*Calamus ciliaris*), etc.

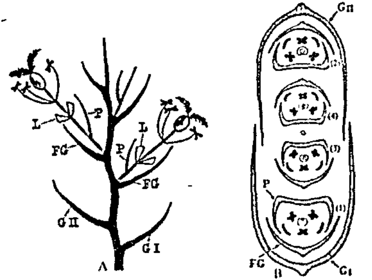
Examples. Fan-palms: palmyra-palm (*Borassus flabellifer*), talipot-palm (*Corypha*—grows to a height of about 24 m., flowers once after about 150 years and then dies), double coconut-palm (*Lodoicea*), a native of Seychelles Islands—bears the largest known seed and fruit; the latter sometimes measuring well over 1m. (see FIG. I/174), oil-palm (*Elaeis guineensis*), and *Hyphaene*—showing dichotomous branching. **Feather-palms:** Indian sago-palm or fishtail-palm or toddy-palm (*Caryota urens*), coconut-palm (*Cocos nucifera*), edible date-palm (*Phoenix dactylifera*), wild date-palm (*P. sylvestris*), betel-nut-palm (*Areca catechu*), cane (*Calamus*), sago-palm (*Metroxylon rumphii*), nipa-palm (*Nipa fruticans*; B. GOLPATA)—a stemless palm, vegetable ivory-palm (*Phytelephas*), and *Zalacca beccarii*—its large cane-like fruits are sold at Shillong market.

FAMILY 7 *Gramineae* (*5,000 sp.*)

Habit—herbs, rarely woody, as bamboos. Stem cylindrical with distinct nodes and internodes (sometimes hollow). **Leaves** simple, alternate, distichous, with sheathing leaf-base which is split open on the side opposite to the leaf-blade; there is a hairy structure at the base of the leaf-blade, called the ligule. **Inflorescence** usually a spike or a panicle of spikelets (FIG. 63); each spikelet consists of one or few flowers, and bears at the base two bracts or *glumes*, one placed a little above and opposite the other; these two are empty, while a third one called *lemma* is flowering, i e. it encloses a flower in its axil; opposite the flowering glume or lemma there is a somewhat smaller, 2-nerved glume called *palea*. The spikelet may be sessile or stalked. **Flowers** usually bisexual, sometimes unisexual, monoecious. **Perianth** represented by two minute scales at the base of the flower, called the *lodicules*; these are regarded as forming the rudimentary perianth. **Androecium**—stamens 3, sometimes 6, as in rice and bamboo; anthers versatile and pendulous. **Gynoecium**—

carpel 1; ovary superior, 1-celled, with 1 ovule; stigmas 2, feathery. Fruit caryopsis. Seed albuminous. Pollination by wind is most common; self-pollination in a few cases, as in wheat.

Floral formula—⚥ $P_{\text{lodicules (2)}}\,A_{3 \text{ or } 6}\,\underline{G}_1$.



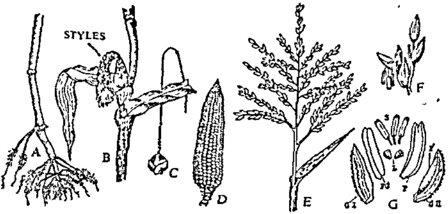
Graminaceae. FIG. 63. *A*, spikelet of a grass; *B*, floral diagram of the same. G_1, first empty glume; G_{11}, second empty glume; *FG*, flowering glume; *P*, palea; *L*, lodicule; stamens and carpels of the florets are apparent.

From an economic standpoint *Graminaceae* is regarded as the most important family as cereals and millets which constitute the chief foodstuff of mankind

Graminaceae. FIG. 64. Rice (*Oryza sativa*). *A*, portion of a branch with sheathing leaves and ligules; *B*, a panicle of spikelets; *C*, 1-flowered spikelet (note the glumes and stamens); *D*, spikelet dissected out—*GI*, first empty glume; *GII*, second empty glume; *FG*, flowering glume; *P*, palea; *L*, lodicules; *S*, stamens; and *G*, gynoecium.

belong to it. Most of the fodder crops which are equally important to domestic animals also belong to this family. The importance of bamboo, thatch grass and reed as building materials and of sugarcane as a source of sugar and jaggery is well known. The importance of sabai grass and bamboo as a source of paper pulp cannot be over-emphasized.

Examples. Cereals such as rice (*Oryza sativa*—FIG. 64), maize or Indian corn (*Zea mays*—FIG. 65), wheat (*Triticum sativum*), *barley* (*Hordeum vulgare*), oat (*Avena sativa*), etc.; millets such as great millet (*Sorghum vulgare*; B. & H. JUAR), Italian millet (*Setaria italica*; B. KAUN), Indian millet (*Panicum miliaceum*; B. & H. CHEENA), little millet (*P. miliare*), pearl millet (*Pennisetum typhoides*; B. & H. BAJRA), *Eleusine coracana* (B. & H. MARUA), job's tears (*Coix lachryma-jobi*)—grains used as an important article of food by the poor hill tribes and also used as beads for ornamental purposes, etc.; sugarcane (*Saccharum officinarum*), thatch grass (*S. spontaneum*; B. KASH; H. KANS), reed (*Phragmites karka*; B. NAL; H. NUDA-NAR), giant reed (*Arundo donax*; B. GAB-NAL; H. NAL-DURA), bamboo



Graminaceae. FIG. 65. Maize or Indian corn (*Zea mays*). *A*, adventitious roots; *B*, female spadix in the axil of a leaf; *C*, female spikelet; *D*, ripe cob; *E*, a panicle of male spikelets; *F*, two pairs of male spikelets; and *G*, a male spikelet dissected out—*GI*, first empty glume; *GII*, second *empty glume; P, palea of the lower flower; FG, flowering glume; P, palea* of the upper flower; *L*, lodicules; and *S*, three stamens of the upper flower.

(*Bambusa*), giant bamboo (*Dendrocalamus*), *Melocanna* (B. MULI-BANS)—ripe berries edible, guinea grass (*Panicum maximum*)—a fodder plant, *P. repens*—a mud-binding plant, lemon grass (*Cymbopogon citratus*)—yields lemon oil, *C. nardus*—yields citronella oil, *C. martini*—yields geranium-oil, *Andropogon squarrosus* (B. & H. BENA or KHUS-KHUS)—roots are woven into summer screen (KHUS-KHUS), sabai grass (*Ischaemum angustifolium*)—paper is manufactured from this grass, etc ; **other common plants:** dog grass (*Cynodon dactylon*), love thorn (*Chrysopogon aciculatus*), *Imperata cylindrica* (B. ULU), *Panicum crus-galli* (B. SHYAMA), and some species of *Paspalum*. It

ay be noted that *Panicum* with about 500 sp., and *Paspalum* with oout 250 sp., are very large genera.

AMILY 8 *Cyperaceae* (3,500 sp.)

he general habit of *Cyperaceae* is similar to that of *Graminaceae* ut the following points should be noted.

Habit—herbs. Stem solid, usually triangular. Leaves simple, alternate, tristichous; ligule absent; sheath closed. The total inflorescence nay be a spike or panicle or globose ead, but the unit of inflorescence s a spikelet. In each spikelet there nay be one or more flowers, but each s borne in the axil of a glume and is ninute in size, unisexual or bisexual. Perianth usually represented by 3 or 6 bristles or scales, or absent. Androecium—stamens usually 3; anthers basifixed, linear. Gynoecium—carpels (3) or (2), syncarpous; ovary 1-celled, with 1 ovule, superior; stigmas 3 or 2, long and feathery or papillose. Fruit a small nut or nutlet. Seed albuminous. Pollination is brought about by wind.

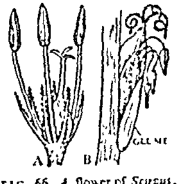


FIG. 66 *A*, flower of *Scirpus*. *B*, the same of *Cyperus*.

Examples: *Cyperus* (400 sp.), e.g. sedge (*C. rotundus*; B. & H. MUTHA), *C. tegetum* (B. MADUR-KATI), *Kyllinga*—common weeds with white globose heads, *Scirpus* (200 sp.), e.g. *S. grossus* var. *kysoor* (B. KESOOR), club rush (*S. littoralis*)—found in the Sundarbans, *S. articulatus* (B. PATPATI), *Carex* (900 sp.). *Juncellus inundatus* (B. PATI), and *Fimbristylis*—common weeds. The family is of little economic importance.

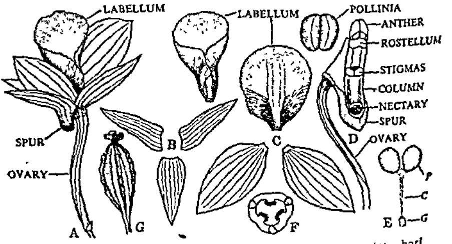
Distinctions between *Graminaceae* and *Cyperaceae*

	Graminaceae	*Cyperaceae*
Stem	cylindrical; solid or hollow	triangular; solid
Leaf	distichous, with ligule; sheath split open	tristichous, without ligule; sheath closed
Inflorescence	spike or panicle of spikelets	spike or panicle or head of spikelets
Glumes	glumes 3, palea 1; lower 2 empty and 3rd one flowering	a flower in the axil of a glume
Perianth	represented by two lodicules	represented by 3 or 6 bristles or scales or absent
Stamens	usually 3; sometimes 6; anthers versatile	usually 3; rarely 6; anthers basifixed
Carpels	only 1, with 2 stigmas	(3) or (2), with 3 or 2 stigmas
Fruit	caryopsis	nutlet

FAMILY 9 *Orchidaceae* (17,000 sp.)

Habit—perennial herbs, commonly epiphytic, some terrestrial, a few saprophytic, e.g. *Neottia*. Mycorrhiza (see pp. 19-20) is common. Epiphytic orchids usually with clinging roots, absorbing roots and hanging roots with velamen (see FIG. I/25). Stems sometimes with pseudo-bulb. Leaves simple, entire, usually thick, frequently sheathing at the base. Inflorescence a raceme, panicle or commonly a spike (long or short). Flowers bisexual, epigynous, medianly zygomorphic, often very showy, with an endless variety of colours and forms, for which they are highly valued and largely cultivated; structure sometimes very complex. Perianth in two trimerous whorls, petaloid and showy; segments of the outer whorl almost equal and so also the two lateral segments of the inner whorl but the posterior one of this whorl is the largest, most conspicuous and often folded and variously shaped, enclosing the column, and is known as the *labellum*. Owing to the twisting of the ovary the labellum, normally posterior, comes round to the anterior side. The labellum is often provided with a *spur*, long or short, which secretes nectar. Androecium—stamens in two trimerous whorls but undergo a considerable amount of suppression or modification into staminodes. Majority of orchids bear 1 stamen (anterior one of the outer whorl)—Monandrae; while some bear 2 stamens (two lateral ones of the inner whorl)—Diandrae. Filament and style united together (gynandrous) and they occur, together with a special organ—the *rostellum*—on a central structure called the *column* (or gymnostemium). The column is an extension of the floral axis, and the rostellum is a sterile stigma which aids pollination. The column with the anther(s) and stigmas stands opposite to and

FIG. 67. Floral diagram of an orchid.



Orchidaceae. FIG. 68. [illegible] hort
of perianth; *C*, inner w[illegible]
ovary and anther; *E*, [illegible]
caudicle; *G*, gland; *F*, ovary [illegible]
(of *Vanda*)—a capsule dehiscing into 6 valves.

facing the labellum. The anther lies on the top of the rostellum, and is attached to the column at its back by a short filament. It is commonly 2-chambered with a pair of pollinia, sometimes 4- or more-chambered with as many pollinia, pollen sometimes granular. The base of the pollinium often extends into a slender stalk called the *caudicle* which may again end in a sticky gland attached to the rostellum. Gynoecium—carpels (3), syncarpous; stigmas 3—the lateral two are fertile and very sticky and the third one sterile (the rostellum); in Diandrae three stigmas are fertile (no rostellum); ovary inferior, commonly cylindrical, 3-valved with 3 ridges (representing mid-ribs of the three carpels), often twisted, unilocular (sometimes falsely trilocular); placentae and numerous extremely minute ovules develop only some time after pollination as a result of stimulus by the process. Fruit a loculicidal capsule, mostly cylindrical, dehiscing by valves and ridges; fruits and seeds take several months, often a year, to develop and mature; hygroscopic hairs often develop from the inner wall of the valves, helping dispersion of seeds. Seeds very numerous, extremely minute and powdery, exalbuminous. *Floral formula*—·|·⚥ P_{3+3}[A_1 or $_2\overline{G}_{(3)}$].

Pollination. Orchids are adapted for cross-pollination by insects in a variety of [illegible]

[illegible] visits a second flower the pollinia on its head point, sometimes by a hygroscopic movement of the caudicle, towards the receptive stigmas; the stigmas being very sticky pull away the pollinia from the body of the insect. Cross-pollination is thus effected. In the same way the insect carries the pollinia from this flower and pollinates a third one. The relative position of the stigmas and the anther, sometimes lying wide apart, often excludes the possibility of self-pollination. Some orchids are also self-sterile. Even then self-pollination in *Orchidaceae* is not uncommon. A few species have cleistogamous flowers. (For details read Darwin's *Fertilization of Orchids.*)

Examples. Epiphytic: *Vanda roxburghii* (B. & H. RASNA), *V. teres*—branches cylindrical, *V. coerulea*, *Dendrobium* (750 sp.)—many in India, e.g. *D. pierardii* (FIG. 68), *D. moschatum*—pink, *D. form*[illegible] *florum*—red, *D. clavatum*—deep red, *D.* [illegible] jointed stem, etc., lady's slipper (*Cypripe*[illegible] *florum*, fox-tail orchid (*Rhyncostylis retusa*) [illegible] orchid, chain orchid (*Pholidota imbricata*), bird's nest orchid (*Neottia*) and coral root (*Corallorhiza*)—saprophytic, *Eria*, *Orchis*, *Bulbophyllum* (450 sp.) and many others common in India, particularly in Assam, [illegible] *Sarcanthus* and [illegible] common in the Sundarbans, *Cattleya* (an American genus)—very ornamental. Terrestrial: *Arundina bambusifolia*, but [illegible] (*Habenaria*—400 sp.)—many species in India, particularly in Assa[illegible] *Phaius wallichii*, *Pogonia*, [illegible] may be noted that *Vanilla*, [illegible] its pods yield the essence vanilla.

PART VIII *Evolution & Genetics*

Chapter 1 ORGANIC EVOLUTION

It is now an established fact that higher and more complex forms of plants and animals have evolved from earlier and simpler forms. At one time, however, it was believed that different species of plants and animals were created in the forms in which they exist today. Even today some are under the impression that minute organisms like bacteria develop spontaneously in putrefying material. Louis Pasteur, a French scientist and founder of the science of bacteriology, proved definitely in 1864 that spontaneous generation is absolutely impossible. Bacteria are present everywhere, and wherever they get a suitable medium they grow. The old view, therefore, is no longer tenable. Moreover, there is evidence to show that plants and animals have evolved from pre-existing forms, and have not been created. Fossil records are particularly instructive in this respect (see p. 645). It has been possible to trace the gradual changes in the types of plants and animals through the successive periods of the earth. The question 'What is the origin of life?' or 'How did the protoplasm, the physical basis of life, first come into being?'—however, remains unsolved. But protoplasm once formed has become continuous from the earliest form of life to the present form through many millions of years.

Life originated in water (in the sea) and it is generally thought that the first organisms were some forms of aquatic bacteria. They could manufacture organic substances from inorganic materials. The energy required for this synthetic process was obtained not from sunlight but from oxidation of iron compounds, sulphur compounds, etc. The next phase in evolution was possibly the appearance of blue-green algae. Primitive unicellular animals might have originated at this stage, and they formed another line of evolution. Later, with the appearance of green algae which could utilize sunlight as a source of energy the trend of evolution leading to higher plants became established. During the earliest period of the earth's existence which comprised several millions of years numerous forms of algae and primitive marine animals formed the dominant feature of the sea. At a later stage of evolution life invaded the land. Organisms of this stage had to depend on both water and land for the completion of their life-cycle. Such organisms are called amphibians, the living representatives being frogs among animals, and mosses and ferns among plants. Later forms are adapted to land conditions.

EVIDENCES OF ORGANIC EVOLUTION

1. Geological Evidence. Actual petrified remains of ancient plants and animals, or impressions left by them in rocks, are called fossils. They are sound evidence regarding the existence of different types of plants and animals in different geological ages and periods of the [illegible] ign (first [illegible] nship, in- [illegible] groups, etc. The surface of the earth consists of layers or strata of rocks formed in different ways in different periods. These strata, thus formed successively, have been found to bear fossils of particular types of plants and animals in their increasing complexity. Thus earlier [illegible] types (see table at p. 696). Fossil records, therefore, are of considerable importance in elucidating the problem of evolution. It is, however, to be noted that fossil records are incomplete for various reasons and as such they reveal gaps in the evolutionary history of plants and animals. [See Part X Palaeobotany.]

2. Taxonomic Evidence. According to resemblances and differences we classify plants and animals into certain well-marked groups, mem- [illegible] evolution. In addition, it is seen that between two or more species of a particular genus there are intermediate forms linking such species (*intergrading species*). If species were constant the occurrence of such forms could not be accounted for.

3. Morphological and Anatomical Evidence. The structural similarities of roots, stems, leaves, flowers and other morphological characters among certain groups of plants, and of bones and other organs among certain groups of animals, and the successive stages in the development of such organs from simpler to more complex forms evidently show the evolutionary tendencies of plants and animals. Morphological similarities in the type of venation, shape of corolla, cohesion or adhesion of stamens and other similar morphological traits among a group of plants are very significant in the problem of evolution. Similarly, the study of types of wood or xylem, development of stele, nature of tracheids and vessels among the higher cryptogams, gymnosperms and angiosperms, and of the development of tissues and nerves among ani[illegible] [illegible] embryo reveals a great resemblance among certain groups of

plants and of animals. The development indicates the evolutionary change that has taken place through successive stages. In all cases one fact at least is common, i.e. the embryo develops from the egg-cell or ovum. Sometimes some organs of plants or animals show a striking resemblance to certain forms from which they have possibly been derived. Thus when a fern spore germinates it resembles a filamentous alga; it then assumes a thalloid form resembl-
[illegible] rog passes
[illegible] osed to be
[illegible] to plants
which may be their ancestors. Thus in Australian *Acacia* the seedling shows a *bipinnate compound leaf like other species of* *Acacia*, although adult Australian *Acacia* has only the winged petiole or rachis (phyllode) without the compound leaf.

5. **Evidence from Geographical Distribution.** It has been seen that many allied species of plants in their wild state remain confined to a particular area. The explanation is that they sprang up from a *common ancestor in that region and could not migrate owing* to some barriers such as high mountains, seas and deserts. Thus we find that double coconut-palm (*Lodoicea*) originated in the Seychelles, traveller's tree (*Ravenala*) in Madagascar, *Eucalyptus* in Australia, cacti in the dry regions of tropical America, cactus-like spurges (*Euphorbia*) in the deserts of Africa, etc., often with allied species near together, showing thereby that all the allied species have evolved from the same ancestral species.

6. **Vestigial Structures.** It is commonly observed that there are certain degenerated parts of plants and animals, which do not serve any useful purpose. Such parts are known as vestigial structures. It is assumed that in the early ancestry of the organisms concerned, such parts were functional and in course of evolution these parts have degenerated after ceasing to function. Thus we find that in *Asparagus* with the development of the green stem and the cladodes the leaves have been reduced to scales. In parasites like broomrape (*Orobanche*) and dodder (*Cuscuta*) leaves have been reduced to scales in the absence of their normal function of photosynthesis. There are many instances of reduction of floral organs, particularly stamens, in many families. The presence of vestigial structures is explained on the basis of the early history of the race and the course of evolution.

MECHANISM OF ORGANIC EVOLUTION

Variation. Variation is the rule in nature. No two forms, belonging even to the same species, are exactly alike. The differences between the individuals of a species are spoken of as **variations**. Variations are the basis on which evolution works. Variations may be of four

types. (*a*) *Variation due to change in environment.* Variation in certain organs of plants or animals in certain directions due to this cause is not, however, believed to be inherited by the offspring. (*b*) *Slow but continuous variation* from generation to generation, however, according to Darwin, is the basis of organic evolution. (*c*) *Discontinuous variation* or mutation, on the other hand, means sudden and sharp variation of one or more individuals of the species in respect of one or more characters. The individuals show no gradations, as in the previous case, but at once assume new forms. The sharp variation of this type is directly inherited by the offspring, and is, according to De Vries, due to change or mutation in genes (see p. 653). As mutation occurs suddenly and spontaneously there is no knowing when a new form will appear by this process. There are many cases of mutation on record. Darwin also observed several cases of wide divergences which he called 'sports'. He thought that sports played only a very minor role in evolution. (*d*) *Variation due to hybridization.* In this process a mingling of two sets of contrasting characters (paternal and maternal) takes place and as a result some of the progeny at least show wider variation.

Adaptation. Adjustment of plants and animals to their environment by means of special structures or of functions is spoken of as adaptation. In ecology numerous instances of adaptations are met with. Adaptation has also an important bearing on evolution. Plants have an inherent capacity to adapt themselves to their environment. Many of them are plastic in nature, and consequently are in a position to adapt themselves to changed conditions according to their needs. This is even more true of animals. It is Lamarck's view that adapted structures are fixed and inherited by the offspring, so far at least as the same environment continues (inheritance of acquired characters). According to this view individuals of the species that invade two or more situations will give rise to a corresponding number of new forms.

H[illegible]ers. Heredity means transmission of [illegible] parent forms to their offspring (the [illegible] like'). This is evident from the fact that a particular species of plants on reproduction gives rise to the same species and to no other. Although no two forms are exactly alike, offspring still bear the closest resemblance to their parental forms, and they also resemble one another most closely with, of course, individual variations. Heredity tends to keep the individuals of a species within specific limits; while variation tends to separate them from one another by differences between them, however minute these may be. Variation, no doubt, is responsible for evolution; while heredity is a check on uncontrolled variation and evolution which would have otherwise given rise to a multitude of peculiar forms

without any distinction between one species and another. When, however, heredity is due to cross-pollination, the chance of a certain amount of variation is inevitable.

Inheritance of characters. In the process of reproduction we find that two reproductive nuclei (i.e. gametes—male gamete of the pollen-tube and egg-cell of the embryo-sac) of opposite sexes, each with n chromosomes, fuse to give rise to the oospore, the embryo and ultimately the mature plant, each with $2n$ chromosomes. Thus inheritance of characters takes place through these nuclei. In 1884 Strasburger and Hertwig established the fact that it is through the chromosomes that characters are transmitted from generation to generation. It is, obvious however, that any particular character of the parent (e.g. colour of flower) cannot be found in the chromosomes; but it may be safely assumed that something representing that particular character must be present in them. That 'something', obscure though it is, is called the **factor** or **determiner** or gene for that particular character, and the genes located in the chromosomes of the gametes or reproductive nuclei are responsible for all the characteristics of the parent plants and their transmission to the offspring. The theory of genes in the chromosomes was introduced by Morgan in 1926. Genes are extremely minute bodies, possibly made of a single protein molecule or at most very small groups of protein molecules.

THEORIES OF ORGANIC EVOLUTION

Pre-Darwinian Ideas of Evolution. The idea of evolution dates back to the earliest period of human civilization. The oldest theories discussed much about the origin of life, but were more or less speculations only rather than facts. These may be summarized under three heads: (1) theory of eternity of the present conditions, (2) theory of special creation, and (3) theory of catastrophism. The believers of the first theory argued that there was neither beginning nor end to the universe. The life forms which existed many millions of years ago have remained unchanged till the present day and would continue in the same throughout eternity. The theory of special creation was preached for many centuries by the Christian Church. The basis of the belief was the account of the creation of the world by God, and everything on this world including animals, plants and man. The theory of catastrophism was introduced by Cuvier, a palaeontologist, who carried out research on fossil fauna for a long time in Paris.

of years due to the changed conditions of the environment.

The idea of organic evolution, although believed to be a modern

one, can be traced back many centuries. The idea of evolution emanated from the researches of many Greek philosophers of whom Empedocles was the first. He believed that organisms did not improve through successive generations but nature tried to produce perfect organisms many times, and during this period unfit forms were eliminated. Then came the great philosopher Aristotle. He believed that there was an inherent tendency among the organisms in nature to attain greater and greater perfection according to the changes in the environment, and that was the reason why there was a perfect gradation from the lowest to the highest evolved in nature. After this period there was a halt in the progress of the idea of evolution until the coming of such evolutionists as Linnaeus, Buffon, Erasmus Darwin, Lamarck, Charles Darwin and others.

Lamarck's Theory: Inheritance of Acquired Characters. The first modern theory of evolution was put forward in 1809 by the French biologist Lamarck (1744-1829). His theory resolves itself into three factors—(*a*) influence of the environment, (*b*) use and disuse of parts, and (*c*) inheritance of acquired characters. Lamarck held the view that environment plays the principal part in the evolution of living organisms. He noted many instances where individuals of the same species grown under different environmental conditions showed marked differences. Plants grown in the shade develop larger leaves [illegible] stem becomes [illegible] o not develop [illegible]. Many plants leading an amphibious life show heterophylly. From such observations Lamarck concluded that plants react to external conditions, and that as a result of cumulative effects produced by the changed conditions through successive generations new species make their appearance. In the case of plants, according to Lamarck, changes in characters (or adaptations) are brought about by the direct action of the environment, and in the case of animals they are brought about by the use and disuse of parts. The use or exercise of certain parts results in the development of those parts; while disuse or want of exercise results in the degeneration of the parts. He further believed that new characters, however minute, acquired in each generation under changing conditions of the environment, are preserved and transmitted to the offspring (inheritance of acquired characters). The classic example cited in this connexion is that of the giraffe. Lamarck's view was that horse-like ancestors of these animals living in the arid region in the interior of Africa had to feed on the leaves of trees. They had necessarily to stretch their limbs to reach up to the leaves. This use or exercise resulted in the lengthening of the neck and the front legs, and thus a new type of animal made its appearance from a horse-like ancestor. His theory is open to certain

objections. One objection is that adaptations due to the influence of the environment are very slight and superficial. Another objection is that the inheritance of acquired characters has not been proved yet. In fact, if seeds collected from plants growing elsewhere for many years under a new environment and acquiring new characters be brought back and grown in their original habitat, the plants are seen to revert to their original forms.

Darwin's Theory: Natural Selection. The next theory of evolution was put forward in 1859 by the English scientist Charles Darwin (1809-82) and published in his *Origin of Species by Means of Natural Selection*. His theory based on a mass of accurate observations and prolonged experiments led the whole scientific world to believe in the doctrine of evolution. His theory, called the *theory of natural selection*, is based on three important factors: (*a*) over-production of offspring and a consequent struggle for existence, (*b*) variations and their inheritance, and (*c*) elimination of unfavourable variations (survival of the fittest).

Struggle for Existence. If all the seeds of any particular plant were to germinate and all seedlings to grow up into full-sized plants, a very wide area would soon be covered by them in course of a few years. If other plants (and also animals) were to increase at this rate, a keen competition, in other words, a struggle for existence, would be set up at once among them because supply of food, water and space would fall far short of the demand. This struggle would soon result in the destruction of large numbers of individuals.

Variations and their Inheritance. It is known that no two individuals, even coming out of the same parent stalk, are exactly alike. There are always some variations, however minute they may be, from one individual to another. Some variations are suited to the conditions of the environment, while others are not. According to Darwin these minute variations are preserved and transmitted to the offspring, although no cause for these variations was assigned by him.

Survival of the Fittest. In the struggle for existence the individuals showing variations in the right directions survive, and these variations are transmitted to the offspring; others with unfavourable variations perish. This is what is called by him 'survival of the fittest'. The survivors gradually and steadily change from one generation to another, and ultimately give rise to new forms. These new forms are better adapted to the surrounding conditions.

Darwin's observations on the variations of domestic animals and cultivated plants served him as a clue to the elucidation of his theory of natural selection Sometimes such extensive changes are found in course of several generations that it becomes difficult to believe that the first form has given rise to the last. Further, for the purpose

of having a desired type, breeders and florists take note of certain variations among individuals, select them for future generations, rejecting and destroying the rest. They grow the selected types, generation after generation, until the desired result is obtained. New types are seen to appear by this process, called *artificial selection*. Many cultivated flowers and vegetables often show a number of varieties, and in course of time these variations become well marked.

Natural Selection. Now Darwin's explanation of natural selection is this: animals and plants are multiplying at an enormous rate. As we know no two individuals are exactly alike, the new forms naturally show certain variations. Some variations are favourable or advantageous so far as their adaptation to the conditions of the environment is concerned, and others are not so. Owing to an excessive number crowding together a keen struggle for existence ensues. And in this struggle those that have favourable variations and are, therefore, better fitted naturally survive, and the rest perish. Through this survival of the fittest the species change steadily owing to preservation and transmission of minute variations, and gradually give rise to newer forms. Darwin called this process 'natural selection' from analogy to artificial selection. It is the environment that selects and preserves the better types and destroys the unsuitable forms.

Pangenesis. This is Darwin's theory by which he assumes that every cell of the plant body or the animal body produces imaginary particles or units, called *pangenes*, which carry in their body not only the normal parental characters but also those acquired during the life-time of an individual plant or animal. Pangenes are formed in all parts of the body, and finally they collect together to form the germ cells. Through these cells all the characters, normal and acquired, are ultimately transmitted from one generation to another. By his pangenesis theory Darwin tried to explain how the characters are carried forward from the parents to the offspring, assuming that somatic cells at a certain stage produce germ cells which in turn produce somatic cells in the next generation.

Although Darwin receives the fullest credit for bringing about the final acceptance of the doctrine of evolution, his theory is open to certain doubts. It is true that natural selection is operative in the preservation of certain forms and destruction of others. Yet some doubts have been expressed regarding the process being the cause of evolution of new species. Some of the reasons for these doubts are as follows. (*a*) Are slight variations of any decided advantage in the struggle for existence? It is only the perfected organs that are helpful to organisms, and not the organs during the process of perfection. (*b*) It is doubtful if slight variations can help the individuals to go beyond the boundary of the species; this has never been found possible by artificial selection in breeding experiments. (*c*) There are many organs which are not of any apparent use to the organisms. (*d*) If only the fittest survive, how is it that many unfit ones still exist? (*e*) If nature selects suitable forms and features, why were not the rest swept out of existence?

Weismann's Theory: Continuity of Germplasm. An ingenious theory explaining the cause of variation and evolution was put forward in

1895 by the German scientist Weismann (1834-1914), a disciple of Darwin. He divided the protoplasm of the animal or plant body into *somatoplasm* which gives rise only to somatic or body cells and *germplasm* which produces the reproductive cells, and they flow as two separate streams through the body of the plant or the animal. Somatoplasm is responsible for differentiation of tissues, development and growth of the individual plant or animal body, and is exhausted and lost at the end of the life-cycle, i.e. it is discontinuous, whereas the germplasm is ever-young and immortal, and is continuous from one generation to another, and is actually the bearer of hereditary characters. Somatoplasm may be influenced by the environment and new characters acquired during the life-time of an individual, but germplasm is not so affected, and, therefore, as is almost universally believed, inheritance of acquired characters is not a possibility. Weismann did not believe in Darwin's pangenesis (see p. 651). During reproduction the fertilized egg gets the paternal germplasm from the sperm and the egg-cell respectively. In the nuclei of both somatic and germ cells there are certain factors which determine the character of the cell. It is believed that each somatic cell has a single factor, whereas a germ cell contains all the factors that are found in the somatic cells of the adult plant or animal. The inheritance of characters by the offspring depends upon these factors of the germ cells only There is always a struggle for existence among these factors, and this results in a *germinal selection.* The stronger factors survive and are readily transmitted from one generation to another. Hence any mutation in the germ-

tion, but it has been criticized by many scientists as purely speculative. Also, it is not a fact, as assumed by Weismann, that germplasm is permanently curtained off from the somatoplasm. With advance in knowledge it has been revealed that chromosomes come in direct contact with somatoplasm during nuclear divisions.

De Vries' Theory: Mutation. Another theory of evolution was advanced in 1901 by the Dutch botanist Hugo De Vries (1848-1935). He held that small variations, which Darwin regarded as most important from the standpoint of evolution, are only fluctuations around the specific type. These variations are not inheritable. De Vries held that large variations appearing suddenly and spontaneously in the offspring in one generation are the cause of evolution. These variations De Vries called 'mutations'. That large discontinuous variations are the causes of organic evolution was first advocated by Bateson in 1894. De Vries strongly supported this view on the basis of his extensive observations. Thus, he observed

an evening primrose (*Oenothera lamarckiana*), introduced from America, growing in a field in Holland. Among numerous plants he found two types quite distinct from the rest. These new types were not described before, and having bred true he regarded them as distinct species—*O. brevistylis* and *O. laevifolia* as he named them. *Oenothera lamarckiana* and the new species were removed to his garden at Amsterdam, and cultivated through many generations. It was found that among thousands of seedlings raised a few (7 new species) appeared that were different from the rest. These when raised, generation after generation, always came true to types. These new forms are known as *mutants*. He propounded a mutation theory as his explanation of evolution. While De Vries agreed with Darwin's view, regarding natural selection weeding out unsuitable forms, he held the view that new species are not formed, as Darwin said, by the slow process of continuous variations. Since then several instances of plant mutations (as well as animal mutations) have been found in nature. Mutation is now known to be due to changes in genes—loss, degeneration, addition, recombination, etc.,—occurring in the gametes, zygote, or somatic cells, ultimately affecting the nature of the mature plant. This is 'gene mutation' (see p. 660) which may also be artificially brought about by treatment with X-rays. The mutation theory of De Vries has been widely accepted.

Chapter 2 GENETICS

Genetics is the modern experimental study of the laws of inheritance (variation and heredity). The name 'genetics' was proposed by Bateson in 1906. Cytology, dealing with the structure, number, behaviour, etc., of chromosomes, is of immense value in understanding many intricate facts connected with genetics since chromosomes [illegible] also to be remembered [illegible] and individuality their [illegible] First scientific studies in genetics were carried out by Gregor Mendel (1822-84), an Austrian monk. He entered a monastery in Brunn (Austria), where he performed his scientific investigations on hybridization of plants, particularly garden pea. The results of his eight years' breeding experiments [illegible] iety of Brunn in [illegible] the transactions [illegible] n. Consequently his work remained unnoticed until 1900, when three distinguished

botanists, Hugo De Vries in Holland, Tschermak in Austria and Correns in Germany, working independently in the same line, discovered its significance and importance. Since then Mendel's work has formed the basis of studies in genetics, and it has been called Mendelism as a mark of honour to Mendel. Mendel died in 1884 before he could see his work accepted and appreciated. The reason is not far to seek. The internal mechanism of the cell leading to heredity was still unknown; chromosomes and genes directly concerned in the transmission of hereditary characters remained undiscovered. Moreover, Mendel's work was overlooked in the excitement caused by the publication of the controversial *The Origin of Species by Natural Selection* by Charles Darwin in 1859.

Plant Breeding. The subject of plant breeding although developed in recent times on modern scientific lines after Mendel's discoveries was known in early times to the Egyptians and Assyrians. During the eighteenth century several crosses were made by many workers and interesting results obtained. New varieties were produced by them by such crosses, but the actual mechanism of fertilization remained undiscovered. About 1830 the development of the pollen-tube and its approach to the ovule were observed. In 1846 Robert Brown, an English botanist, did considerable work on this problem. But it was in 1884 that Strasburger clarified the whole process of fertilization and the transmission of hereditary characters through the reproductive nuclei, i.e. male gamete and egg-cell, which are directly concerned in fertilization. In the nineteenth century Gartner in Germany made extensive crosses—thousands of them—involving nearly 700 species and obtained about 250 hybrids. His work was published in 1849.

Plant breeding consists in producing offspring by artificially pollenizing the stigma of another flower according to certain principles. Two varieties or species or even genera differing from each other in one or more characters may thus be crossed and the results studied. The offspring or hybrids, as they are called, will usually show in the first generation some of the characters of each parent or will be intermediate between the two parent forms. In the subsequent generation the dormant characters are seen to appear in the offspring. The offspring resulting from the crossing of red-flowered and white-flowered plants, of tall and dwarf plants, and of other plants with contrasting characters are said to be **hybrids**. It is often seen that the hybrids are more vigorous than their parents. This phenomenon is

by Shull

bined in

is called,

by selecting parent plants with suitable characters. Thus new varieties

of economic and ornamental plants can be produced by hybridization. Herein lies the importance of plant breeding (see pp. 663-5).

Mendel's Experiments. Mendel selected for his work the common garden pea. In pea he found a number of contrasting characters—flowers purple, red or white; plants tall or dwarf; and seeds yellow or green, smooth or wrinkled. He concentrated his attention on only one pair of characters at a time, and traced them carefully through many successive generations. In one series of experiments he selected tallness and dwarfness of plants. The results he achieved in these experiments were the same in all cases. It did not matter whether he took the dwarf plant as the male one and the tall plant as the female one or vice versa (reciprocal crosses).

MENDEL'S MONOHYBRID RATIO

Parents	TT tt
Parental gametes	T × t
F_1 generation (hybrid)	Tt
F_1 gametes	T (male) t T (female) t ×
F_2 generation	TT Tt Tt tt
F_3 generation	TT TT Tt Tt tt TT Tt Tt tt tt

Monohybrid Cross. Mendel selected a pea plant, 2 metres in height, and another plant, 0.5 metre in height. He brought about artificial crossings between the two. In due course seeds collected from the crossed plants were sown next year. The hybrid progeny that came up were all tall (with dwarf character remaining latent in them and, therefore, impure tall). This generation was called the first filial generation or F_1 generation. Of the two contrasting characters the one that expressed itself in the F_1 generation was called **dominant** by Mendel, while the other character that remained suppressed (but not absent in the hybrids) was called **recessive** by him. All the F_1 plants were inbred, and so also those of the successive generations. Seeds were collected from them and sown next year. It was seen that they gave rise to a

only. Seeds were collected separately from the tall plants and sown separately. They gave rise to the next generation or F_3 generation. It was seen that one-third of the talls bred true to type producing talls only, while two-thirds of the talls again split up in the same ratio of 3:1. The F_2 ratio may then be expressed as 1:2:1, i.e. one-fourth pure talls, half mixed talls, and one-fourth pure dwarfs. This scheme of inheritance is expressed symbolically in the table on p. 655. It is now the custom to use a capital letter to denote the factor for the dominant character—T in this case, and the corresponding small letter for the recessive character—t in this case.

Mendel's Laws of Inheritance. From the results of his experiments on crossings Mendel formulated certain laws to explain the inheritance of characters, as follows.

(1) **Law of Unit Characters.** This means that all characters of the plant are units by themselves, being independent of one another so far as their inheritance is concerned. There are certain factors or determiners (now called *genes*) of unit characters, which control the expression of these characters during the development of the plants. The factors occur in pairs; this is evident from the fact that F_1 generation splits in the F_2 generation into tall and dwarf individuals.

(2) **Law of Dominance.** As already mentioned, of the two contrasting characters the one that expresses itself in the F_1 generation is called *dominant*, while the other character that remains suppressed in the F_1 generation is called *recessive*. The latter, however, is always present in the F_1 individuals. Thus in the previous experiment tallness is the dominant character and suppressed dwarfness the recessive character. Mendel reasoned that there must be two factors

in the chromosome). In the F_1 generation one factor masks the expression of the other factor, and, therefore, one character becomes

(3) **Law of Segregation.** It is evident that the F_1 zygote contains factors for both the alternative characters, namely, tallness and dwarfness, although tallness has expressed itself in the F_1 generation. These factors remain associated in pairs in the somatic cells of the F_1 individuals throughout their whole life. Later in the life-history when spores—pollen grains and megaspores (and subsequently gametes) —are formed as a result of reduction division, the factors located in homologous chromosomes become separated out, and each of the four spores (and gametes) will have only one factor (tallness or dwarfness)

of the pair but not both, i.e. a gamete becomes *pure* for a particular character. This law is also otherwise called the law of *purity of gametes*.

Phenotype and Genotype. When two individuals are similar in their [illegible] m morphological study) but differ [illegible] re referred to as phenotypes, and [illegible] is the same (evident from cytological study), they are referred to as genotypes. Thus in Mendel's previous experiment TT and Tt individuals of the F_2 generation are alike externally although they differ from each other with respect to their genes; these individuals, therefore, belong to the same phenotype. But because of their differences in genetic composition they are said to belong to different genotypes, TT to one and Tt to another. It may further be noted that when the individuals have [illegible] be *homozygous*, and when dis- [illegible] T and tt individuals are homo- [illegible] ozygous.

Mendel also experimented on other pairs of alternative characters, and he found that in every case the characters followed the same scheme of inheritance. Thus in garden pea he discovered that a coloured flower was dominant over a white flower; yellow seed over green seed; and smooth seed over wrinkled seed.

Back Cross. Crossing back F_1 plants (hybrids) to either of the two parental types, normally a recessive type, is called a back cross. It is otherwise called test cross because by this method it has been found possible to test the purity of a particular race of plants and also the gametic proportion of F_1 hybrids. Back crosses are now extensively employed in experimental plant breeding. It is evident that only two alternative back crosses are possible—either with the [illegible] type. In the former [illegible] sive character are seen to appear in the ratio of 1:1, i.e. one-half of the total population dominant and one-half recessive. To take a [illegible]

[illegible] numbers. Therefore, in such a back cross only four combinations are possible, viz. Tt, Tt, tt and tt, i.e. the ratio of tall (impure Tt) to dwarf (pure tt) is 1:1. This ratio has been verified by thousands of back crosses.

Xenia. The term xenia, first introduced by Focke in 1881, is used to indicate the direct influence of foreign pollen on the endosperm and other seed-characters of the crossed plant in the same generation, i.e. on the same mother plant in the same year. Such influence has also been noted on certain maternal tissues outside the embryo and the endosperm, as on the size, colour, flavour of fruits like date-palm, apple, orange, etc.; such a phenomenon has been called *metaxenia* by Swingle in 1926. Swingle further suggested in 1928 that this effect might be due to the secretion of hormones by the embryo and the endosperm. Thus certain gametic differences have been noticed in some seeds developing directly on the mother plant. In such cases the dominant factors of the pollen are believed to have been directly introduced through crossing—natural or artificial, and corresponding characters have expressed themselves in the seeds directly borne by the mother plant. For instance, in maize the cob with wrinkled grains is seen to produce some smooth grains on it here and there, these are hybrids which later breed in the Mendelian ratio of 3:1. Similarly, coloured grains are occasionally found on white- or golden-grained cob. There are several instances of xenia on record.

Dihybrid Cross. For the dihybrid cross two pairs of contrasting characters are taken into consideration at a time. Mendel selected

MENDEL'S DIHYBRID RATIO

Parents	TRTR ↓ trtr ↓
Parental gametes	TR × tr
F_1 generation (hybrid)	TRtr
F_1 gametes	TR Tr tR tr

(See below for the next generation)

Male gametes of F_1

Female gametes of F_1	TR	Tr	tR	tr
TR	TRTR (tall-red) [1]	TRTr (tall-red) [2]	TRtR (tall-red) [3]	TRtr (tall-red) [4]
Tr	TrTR (tall-red) [5]	TrTr (tall-white) [6]	TrtR (tall-red) [7]	Trtr (tall-white) [8]
tR	tRTR (tall-red) [9]	tRTr (tall-red) [10]	tRtR (dwarf-red) [11]	tRtr (dwarf-red) [12]
tr	trTR (tall-red) [13]	trTr (tall-white) [14]	trtR (dwarf-red) [15]	trtr (dwarf-white) [16]

F_2 generation

a tall plant with red flowers —TRTR and a dwarf one with white flowers—trtr, their respective gametes being TR and tr. Four unit characters are, therefore, concerned in the dihybrid ratio. Factors for tallness or dwarfness and red flowers or white are independently inherited. Artificial crossing was brought about between these two plants. In the F_1 generation all individuals were tall with red flowers —TRtr because tallness is dominant over dwarfness, and coloured flowers dominant over white, subsequently their gametes bearing

the following proportions: 9 red talls, 3 white talls, 3 red dwarfs, and 1 white dwarf. This 9: 3: 3: 1 is the dihybrid ratio.

Nos. 1, 2, 3, 4, 5, 7, 9, 10, 13 are tall-red =9
Nos. 6, 8, 14............ are tall-white =3
Nos. 11, 12, 15......... are dwarf-red =3
No. 16................ is dwarf-white =1

. 11 and 16 are *homozygous* ing true; while the rest are ar gametes), segregating in generation.

No. 1 (TRTR) will breed true for tall-red
No. 6 (TrTr).................. tall-white
No. 11 (tRtR).................. dwarf-red
No. 16 (trtr)................... dwarf-white

Polyhybrid Cross. In this way Mendel extended the number of characters; for example, when three pairs of contrasting characters were taken—tall and dwarf, red flower and white, and smooth seed and wrinkled, it was found that in the F_1 generation all individuals were tall with red flowers and smooth seeds with the factors TRStrs—three dominant and three recessive. They evidently produced eight kinds of gametes with triple factors each, e.g. TRS, TRs, TrS, Trs, tRS, tRs, trS, trs. When inbred they formed a possible range of 64 (8x8) types of plants in the F_2 generation. When analysed they were found to have split up in the following proportion—27 (tall-red-smooth): 9 (tall-red-wrinkled): 9 (tall-white-smooth): 3 (tall-white-wrinkled): 9 (dwarf-red-smooth): 3 (dwarf-red-wrinkled): 3 (dwarf-white-smooth): 1 (dwarf-white-wrinkled).

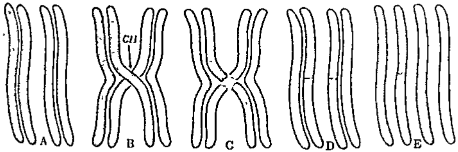
Linkage. Chromosomes are regarded as the bearers of hereditary characters. Each of the ... is made up of several *genes*, These genes At a certain nes come in

close association in twos and interchange their parts, and while doing so some of the genes of one chromosome go over to the other chromosome. But some genes of a particular chromosome, whether paternal or maternal, tend to remain together from generation to generation, i.e. these genes are linked together in inheritance even after crossing over (see p. 661). Such a phenomenon where genes tend to remain together in inheritance is known as **linkage**, as first noted by Morgan in 1910. For example, in sweet peas, as first noted by Bateson and Punnett in 1906, there are two flower-colours—*purple* and *red*, and two types of pollen—*long* and *round*. Purple colour and long pollen behave as dominants to red and round respectively, each character being represented by a single gene in inheritance. In a cross between purple long and red round the F_1 individuals are all purple long. In the F_2 generation it is found that the parental combinations, i.e. purple long and red round are much more numerous than the expected Mendelian ration of 9:3:3:1. This unexpected number is explained as due to the fact that the genes for purple long as well as red round remain together, i.e. linked in inheritance, and hence more of these parental combinations are produced. In tomatoes it has been found that there are two factor pairs Rr and Yy governing the fruit-colour. R factor produces red flesh and is dominant over factor r which produces yellow flesh. The dominant factor Y produces yellow colour and the recessive factor y represents colourless fruit. It has been found that the factor pair Yy is linked with the size of the fruit. There is a close association of y genes with large fruit. In maize or Indian corn ten linkage groups have been noted, e.g. coloured and full endosperm, colourless and shrunken endosperm, etc. Generally the number of linkage groups in any plant or animal is the same as the number of chromosome pairs. Linkage is not, however, always very complete, i.e. a few linked genes break apart and recombinations take place.

about a change in the character. In many instances it has been seen that red-eyed species of *Drosophila* produced white-eyed individuals, or normal *Oenothera*

instances of gene mutations on record.

Crossing Over. Each chromosome consists of a pair of chromatids. At pachytene stage of meiosis the homologous chromosomes pair but subsequently at diplotene stage they separate again remaining attached at one or few points known as chiasmata. At these points a break may occur due to the twisting of the chromatids about each other; as a result a part of a chromatid of one chromosome goes over to a chromatid of the other chromosome, and this interchange of the parts of the chromatids of a pair of chromosomes is known as



matids at chiasma and crossing over (at diakinesis or at metaphase); *D*, dissociation of two newly constituted chromosomes (at anaphase); *E*, separation of four chromatids (at the end of second division), each entering into a daughter nucleus (spore or gamete)

crossing over. Crossing over brings about parental combinations of linked genes. Linkage is not, however, always very complete, thus resulting in separation of a few linked genes and appearance of new combinations. It is to be noted that normally crossing over takes place between only two chromatids of the two homologous chromosomes, while the other two chromatids of the chromosome pair preserve their own identity and pass on to the gametes intact. Temperature, X-ray and radium treatment have a profound influence on the frequency of crossing over.

become possible; XX (female offspring) and XY (male offspring). Now a question pertinently arises. Is it possible by any means to bring about any desired combination at will? The answer is a definite 'no' at the present state of our knowledge. In addition to the common type mentioned above there are other types also. For example, in birds the female has XY, while the male has XX, i e. the order is seen to be reversed. In liverworts, mosses and some algae there is an X in the female, and a Y in the male. They combine into XY in the zygote and the succeeding sporophyte. There is another type in which the female has a pair of X-chromosomes, while the male has only one X-chromosome. Thus one sex is XX (female), while the other is XO (male). Such a type is known as the XO type.

Chromosome Mechanism in Heredity and Evolution. Recent work of Morgan and his colleagues on a fruit-fly (*Drosophila melanogaster*) has led them to put forward the chromosome theory of heredity. According to this theory chromosomes are the bearers of hereditary characters, and the *genes* which are responsible for the production of characters are arranged in a linear fashion in the chromosomes. The continuity of chromosomes throughout the life-cycle of a plant is evident. Plants reproduce by the fusion of male and female gametes, and the zygote so formed develops into the seedling and the mature plant. So the parental characters must be transmitted to the offspring through these gametes. The somatic (body) cells of the sporophyte have $2n$ chromosomes, of which n chromosomes are of paternal origin and n of maternal origin. When the gametes are produced the sporophytic number ($2n$) is reduced to half (n) by meiosis so that each gamete has n chromosomes. As soon as the gametes fuse to form the zygote, $2n$ are regained. The inheritance of the parental characters by the offspring is carried on by the genes which are ultra-microscopic particles occurring in pairs (one paternal and one maternal) in linear series in the chromos [illegible]
genes become equally appo [illegible]
cular plant or animal has a [illegible]

[illegible]

characters of a plant or an animal are, however, always influenced [illegible]

[illegible]

or even the appearance of new genes or due to changes in the proportion of genes, known in all cases as 'gene' mutations. The cause

of these changes is as yet unknown. The simple case of 'gene' muta-

suddenly appeared in the field from normal plants, and these subsequently bred true. These were new species which, according to De Vries, had evolved only by 'gene' mutation. Sometimes a red- or blue-flowered species is seen to give rise suddenly to white-flowered species. The old gene, it is assumed, has changed and a new character

ploidy, e.g. wheat, maize, evening primrose, rose, cotton, tomato, *Datura*, etc. Polyploid plants often show large variations and are distinct from normal plants with diploid chromosomes. Polyploidy may lead to the development of perennial types from annual types, of disease-resistant variety of tobacco, of seedless varieties of certain fruits like banana, orange, grapefruit, tomato, water melon, etc., of high-yielding varieties of wheat and cotton, and of better varieties of root-crops such as sugar-beet, turnip, radish, etc. Polyploidy has been found to occur in several wild and cultivated plants under natural as well as artificial conditions such as lowering or raising of

somes, and *Datura* with 25 ($2n+1$) chromosomes. It is thus seen that chromosomes play an important part in the evolution of new forms.

Economic Importance of Plant-breeding. Plant-breeding has been scientifically developed to such an extent in recent years that it is now recognized as the best practical method for the improvement of

lity, colour, size, total yield and other useful characters. It has been found possible by the application of this method to combine the desired characters of parent forms and evolve new types far better than original types in many respects. Babcock, a leading geneticist, even goes so far as to say that plants can almost be made to order. This being so, the subject is considered to be of utmost importance in agriculture and to a great extent in horticulture. By following practical methods of plant-breeding considerable improvements have

already been achieved within the last few decades; for example, hardy, rust-resistant and high-yielding types of wheat plants have been evolved, and the milling and bread-making qualities of wheat grains considerably improved. Several new varieties of rice with higher yield and better quality have been brought into existence. In tobacco the number of leaves per plant and their size and quality have been enhanced. Pea, bean, many vegetables, pulses, oil-seeds, etc., have been considerably improved. Fruits like apple, grapes, peach, pear, plum, orange, strawberry, etc., have similarly been much improved. In fibre-yielding plants like jute, cotton, flax, etc., better quality of the fibre (length, strength and fineness) and also higher yield have already been achieved. New types of maize, potato and tomato—high-yielding and rust-resistant—evolved recently in America are also some of the numerous achievements in this direction. In Russia new varieties of summer and winter wheats and 'perennial' wheat (results of crosses between varieties of wheat and couch-grass), wheat-*Elymus* (result of cross between wheat and *Elymus*—a kind of grass), and barley-*Elymus* (result of cross between barley and *Elymus*) are some of the outstanding features of work in this line. In India also a considerable amount of work has been done in this line on rice, wheat, millets, maize, sugarcane, pulses, oil-seeds, cotton, tobacco, jute, flax, hemp, etc., and improved strains combining high yield, good quality and resistance to pests and diseases evolved by breeding. Pusa wheats deserve special mention in this connexion. Several new Pusa varieties tolerant to rust and resistant to smut and at the same time very high-yielding evolved at the the Indian Agricultural Research Institute[1] are outstanding successes. A wheat, New Pusa 4 (NP4), evolved at Pusa, was awarded the first prize in several international exhibitions in America, Australia and Africa. The most important achievement of the Institute in New Delhi is the development in recent years of hybrid millets and maize strains yielding 50% more than the common varieties. Some new strains of wheat have also been evolved by this Institute to suit different climatic regions of India. A hybrid maize,

[1] The Indian Agricultural Research Institute (commonly known as Pusa Institute) was established in 1905 at Pusa in Darbhanga (Bihar) on the liberal donation of £30,000 by an American philanthropist, Mr. Henry Phipps At this Institute early work on the improvement of wheat by selection and breeding was carried out by late Sir Alfred Howard with considerable success. The laboratory buildings having been irreparably damaged by the great Bihar earthquake in 1934 the Institute was transferred to New Delhi in 1936. At present it has six sub-stations at Pusa (Bihar), Karnal (East Punjab), Simla (Himachal Pradesh), Poona (Maharashtra), Indore (Madhya Pradesh) and Wellington (Madras).

evolved through hybridization are some of the special achievements of this Institute. A recent success is the production of a sweet-flavoured tomato with a high vitamin content (result of a cross between a cultivated tomato and a wild South American species). New types of sugarcane evolved at Coimbatore in South India have already become world-famous. These sugarcanes are mainly responsible for the improvement of the sugar industry in India. Although much has already been achieved there is still ample scope for improvement of several crops for food and industry.

It is evident from the foregoing that the subject of plant-breeding has grown so much in economic importance that the agricultural and plant-breeding stations all over the world have embarked on programmes of artificial plant-breeding for enhancing the quality and yield of particular crops, and the power of resistance to pests and diseases.

PART IX *Economic Botany*

Chapter 1 GENERAL DESCRIPTION AND ECONOMIC PLANTS

Economic Botany deals with the various uses of plants and plant products for the well-being of mankind. It also includes the various practical methods adopted for their improvement. Economic uses of plants are varied and the scope for improvement is immense to meet man's ever-increasing need. The primary needs of mankind are of course food, clothing and shelter which in their basic forms are supplied by nature and subsequently improved upon by man by the application of his scientific knowledge. The gifts of nature are almost unlimited and a variety of useful products are obtained from the plant kingdom.
Methods of Improvement. The methods commonly employed for improvement of crops with regard to their quality, yield, etc., are: (1) pure line selection, (2) breeding (see pp. 654 & 663), (3) improved methods of cultivation, (4) selection and use of 'quality' seeds, (5) proper use of chemical fertilizers and manures, (6) judicious selection of crops for a particular locality, (7) intensive and extensive cultivation, (8) protection against diseases, pests and destruction, and (9) proper irrigation—*major* by dams and barrages across perennial rivers diverting the water through canals, and *minor* by wells, tube-wells and tanks with the help of Persian wheels, MOTS and pumps.

Economic plants are numerous and have a variety of uses. Many of them occur in a natural state, particularly in forests; while a good number of them are cultivated for food and industry. Such plants may be classified under the following heads: (A) food—cereals and millets, (B) pulses, (C) vegetables, (D) oil-seeds, (E) fruits, (F) sugar, (G) spices, (H) medicinal (drug) plants, (I) beverages, (J) timber, (K) fibres, (L) rubber, and (M) paper. It may be of interest to note in this connexion that India is the largest producer of tea, sugarcane and groundnuts; Pakistan of jute; China of rice; U.S.A. of corn and cotton; Brazil of coffee; Ghana of cocoa; and U.S.S.R. of beet sugar. It may also be noted that the most important exchange earners of India are tea, jute goods and cotton cloth in their order of importance. These three together represent in value nearly half of India's total exports.

A. **Food.** Food may be classified into the following groups: (*a*) heat- or energy-producing food having high calorific values such as carbohydrates and fats; (*b*) body-building food such as proteins; (*c*) protective food such as vitamins and some minerals; and (*d*) *luxury food*

such as confectioneries, etc. The energy value of food is expressed in terms of calories. A calorie is the amount of heat needed to raise 1 kilogram of water through 1°C. It may be noted that 1 gm. of carbohydrate yields about 4 calories, and 1 gm. of fat about 9 calories. The daily requirement of a man of average weight, doing moderate work, is about 3,000 calories which must be obtained from the food he eats. It is evident that food plants must contain sufficiently high percentages of carbohydrates, proteins, and fats and oils together with vitamins and essential minerals. All cereals and millets [illegible] hey belong to [illegible] eals constitute [illegible] Major cereals are rice, wheat, and maize, and major millets (smaller-grained ones) are JUAR or CHOLAM (*Sorghum*), RAGI (*Eleusine*) and BAJRA (*Pennisetum*). For proper nutrition of the human body, however, a balanced diet consisting of cereals, vegetables, pulses, vegetable oils, sugar, fruits, and also milk and milk products, and according to habit and custom fish, meat, eggs, etc., is indispensable Among the important food crops of India cereals occupy about 60% of the total area under cultivation, pulses about 18% and oil-yielding plants about 8%.

1. Rice (*Oryza sativa*) is the major agricultural crop in India occupying about 36% of the total area under cereals, covering over 32 million hectares, which is the world's largest rice area. Rice is the staple food of India and the principal article of diet in tropical Asia and in fact feeds over 60% of the world's population. It contains 70-80% of starch, 7% of proteins and 1.5% of oils, and vitamins (commonly A, B and C) in the pericarp. In polished rice these vitamins are removed. Rice has been cultivated from time immemorial. There are about 7,000 varieties of rice, of which about 4,000 varieties occur in India alone, derived from the old wild form which is still found. Although many new better varieties of rice—finer, higher-yielding and disease-resistant—have been evolved in India by the Agricultural Departments and the Central Rice Research Institute at Cuttack (Orissa) by means of selection and hybridization the annual [illegible] with cowdung, ashes and tank-earth, and by the use of chemical fertilizers like sulphate of ammonia and bonemeal the yield increases much above the average. The average yield of rice in India is more or less 1,450 kg. per hectare per year, much more under the Japanese method of cultivation and also under some special conditions, as against 3,117 kg. and 3,406 kg. in Egypt and Japan respectively, where fields are heavily manured. Rice straw is a fodder for cattle.

Cultivation. 2 or 3 croppings are practised in India according to the conditions of the soil and the climate. Indian rice-fields generally remain undermanured. Common seasonal varieties are AUS or summer rice, AMAN or winter rice and BORO rice in between, with many sub-varieties of each.

1 *AUS* or summer rice is coarse, difficult to digest and low-yielding, as compared to AMAN. AUS paddy prefers high land without waterlogging. Sandy banks of rivers with silt deposits is ideal for its cultivation. After ploughing and cross-ploughing the fields are made ready. Paddy grains are sown in seed-beds or in the fields in early May and watered regularly. When the seedlings are about 23 cm. high they are transplanted to water-soaked fields after a few showers of rain. The seedlings are commonly planted 15-23 cm. apart in small bunches of 3-5, or even singly, sometimes, however, in large bunches of 15 or so in flooded areas. AUS paddy is also broadcast, and transplanting is avoided; the yield, however, is low in this case. The time for harvesting is August-September before the grains fully ripen as they shed very easily. Paddy is threshed out of the stalk by beating or by trampling by cattle. The yield of AUS paddy varies from 1,075-2,240 kg per hectare per year.

2. *AMAN* or winter rice is better in quality, finer and more easily digestible. AMAN paddy prefers a low-lying land with clay soil. The general mode of cultivation is almost the same as that of AUS. Paddy grains are sown in prepared seed-

[illegible]

lizers, as in the case of AUS, improves yield. AMAN paddy is harvested in November-December. It can be stored for months before threshing. Its yield is much heavier, being about 2,912-4,480 kg. per hectare per year.

3. *BORO* paddy is a minor crop. But two croppings may be practised: (*a*) KHARIFF or rain crop sown in June-July and harvested in September-October; and (*b*) RABI or winter crop sown in October-November and harvested in March-April The grains may be broadcast and seedlings later transplanted. The yield is 1,790-2,240 kg per hectare per year.

4. Deep-water paddy is grown in low-lying areas during the rains, but not widely. It can stand water to a depth of 1.5-3 metres or even more. The peculiarity is that with the rise of water level the plant grows quickly—20-30 cm. a day, but if it gets completely submerged it rots. The yield is low.

JHUM Cultivation. It is the practice with some hill tribes to select the best [illegible]

2. Wheat (*Triticum sativum*) is the second staple crop of people in India, and the principal article of diet in Western countries. There are several varieties of wheat. They may be broadly classified into *hard* and *soft*. The former varieties are adapted for making SUJI and ATTA, while the latte [illegible] extensively cultivate[illegible] Punjab. Soft wheats [illegible]

Indus, and harder varieties elsewhere. Grains are sown in October-December and the crop harvested in March-May. Wheat is a universal crop, i.e. it can be successfully grown in both temperate and tropical countries. The average yield of wheat in India is poor—about 677 kg. per hectare per year, against 1,396 kg. in Canada, 1,708 kg in Japan, and 2,468 kg. in Great Britain. Several new varieties of wheat —hardy, disease-resistant, high-yielding, with better milling and bread-making qualities—have been evolved in India (see p. 664). Some of the best wheats are grown in Australia, America and Russia. Average chemical composition is: starch—66-70%, proteins—12% and oils—1.5%. Wheat straw is a fodder for cattle Wheat prefers a clay-loam or sandy loam, and thrives under irrigation. Saltpetre is the best manure for wheat.

3. Maize or Indian Corn (*Zea mays*) is an important cereal food for poor people. It is cultivated both in the hills and the plains and does well both in hot and cold climates. There are several varieties and hybrids. The usual sowing season is April-May and the harvesting season July-August. Each plant commonly bears one cob, sometimes two, and the average annual yield per hectare is 986 kg.; with some good varieties the yield has gone up to 1,570 kg. Some new hybrids of maize have been evolved in India, which are very high-yielding, disease-resistant, sweetish and nutritious (see p 664). Maize

corn-flour; they are also powdered into starch. The young tender grains are nutritious and may be taken raw, roasted or boiled in milk. Of all cereals maize contains the largest amount of oils. The average chemical composition is: starch—68-70%, proteins—10% and oils—3.6-5%. Maize prefers a high open land for its cultivation, and requires manuring as it exhausts the soil. Leaves and stems form a good fodder and the grains a nutritious food for farm animals.

4. *JUAR* or *CHOLAM* (*Sorghum vulgare*) is the best of all millets. It affords nutritious food, nearly as good as wheat. It is cultivated extensively in South India, and also in Maharashtra and Gujarat. The plants are as tall as 3-4 metres. The average annual yield per hectare

proteins—9% and oils—2%. Grains are generally sown in June-July, and the crop harvested in October-November. It takes 4-5 months to mature, and two croppings are generally practised. JUAR is a good fodder crop.

5. *RAGI* or *MARUA* (*Eleusine coracana*) is an important food crop of Mysore State, and is cultivated extensively in Mysore and Madras,

and to some extent in Bombay, Bihar, Uttar Pradesh, and Punjab. RAGI being a short duration crop 2 or 3 croppings are practised a year. Commonly it is sown in June-July and harvested in August-September. The plants are 0.6-1 metre in height. The annual yield per hectare is 785-1,120 kg., sometimes well over 2,200 kg. in properly irrigated red soil. The average chemical composition is: starch —73%, proteins — over 7% and oils—1.5%. The grains are difficult to digest. The straw is a nutritious fodder for cattle.

6. *BAJRA* (*Pennisetum typhoides*) is another important millet, and is cultivated almost throughout India. The plants are 1-2 metres in height, and the dark-brown spikes 15-23 cm. in length. The crop takes 3 months to mature. The average annual yield per hectare is 560-670 kg. or a little more under irrigation. The average chemical composition is: starch—71%, proteins—10% and oils—over 3%. It grows in regions with low rainfall. Commonly the grains are sown in May and the crop harvested in July-August. The grains often require husking like rice. They are cooked like rice or ground into flour. The straw is not commonly used as a fodder.

B. Pulses. As food grains pulses (family *Papilionaceae*) stand next to cereals. They are cultivated extensively in India as winter crops in rotation with cereals. Pulses occupy about 18% of the total area under cultivation. They are valued as food because of their high protein content averaging 22-25% (in soybean as high as 42-47%), starch content about 58% and oil content 2% or more; in gram, however, the oil content may be as high as 5%. They contain vitamins A, B and C, particularly in sprouted seeds. The pulses commonly used in India are gram, pea, black gram, pigeon pea and lentil. With the exception of pigeon pea (which is a shrub) all the rest are annual and form short-duration crops. Pulses are widely used in various culinary preparations, particularly DAL. The plants form good fodder. Having root-nodules for nitrogen-fixation they form excellent green manures.

1. **Gram** (*Cicer arietenum*) is cultivated extensively in India. The crop matures in three months. Gram is a nutritious food but somewhat difficult to digest. It is commonly used as a DAL. It is also boiled, fried or roasted. Soaked seeds are fed to horses for strength. Apart from its high protein content it is also rich in oil, and is a good source of vitamin A. Average chemical composition is: starch—58%, proteins—24.5% and oils—5%. The average annual yield per hectare is about 500 kg., sometimes going up to 900 kg. or more.

2. **Pea** (*Pisum sativum*) is another common pulse but not very extensive in India. It is relished as an occasional substitute for other pulses. Green seeds are eaten raw or boiled. Average annual yield per hectare is 280 kg. It is cultivated mainly in Northern and Eastern India.

3. **Black Gram** (*Phaseolus mungo*) is one of the best pulses grown throughout India. The plants have a trailing habit. The seeds are usually dark-brown in colour. The average annual yield per hectare is 500 kg. The average chemical composition is: starch—54%, proteins—22% and oils—1%. The proteins of black gram are more easily digestible and are almost as good as meat. Apart from its use as DAL black gram is used for preparations of various forms of pies. PAPPAD is made from this pulse.

4. **Pigeon Pea** (*Cajanus cajan*) is a perennial shrub grown as a pure crop or mixed crop, and widely cultivated in India. Sowing is done in May-July, and within six months it bears pods. The crop is harvested in December-March. Commonly two varieties are distinguished—one with longer pods and the other with shorter pods. The average annual yield per hectare is 450-900 kg. Average chemical composition is: starch—57%, proteins—22% and oils—about 2%. It is used as DAL. In South India it is an important item of diet, while in Upper India it is used only occasionally.

5. **Lentil** (*Lens culinaris*) is an important pulse of Northern and Eastern India. The crop takes only three months to mature and is generally harvested in February-April. The average annual yield per hectare is 450-670 kg., going up to 900 kg. under irrigation. In Eastern India this pulse is in almost daily use and is nutritious. Average chemical composition is: starch—58%, proteins —25% and oils—1-1.5%.

C. **Vegetables.** (*a*) Leafy vegetables like cabbage, lettuce, spinach, etc., are rich in vitamins, usually A, B, C and E, and should, therefore, be included in the daily diet; and (*b*) tuber crops are fleshy underground roots or stems laden with a heavy deposit of food materials. Some of the common ones are as follows.

1. **Potato** (*Solanum tuberosum*—family *Solanaceae*) is a native of Peru (South America), and was first introduced into India by the Portuguese in the early part of the 17th century. Potato is an underground stem-tuber, and is cultivated extensively in India in the hills as well as in the plains, usually during cold months. But it may be grown both as a summer crop and a winter crop. Potato is a universal article of diet all over the world. It is an excellent food and is used in a variety of culinary preparations. The average yield is in the neighbourhood of 7-8 tonnes per hectare per year, often double this quantity under suitable conditions. On the whole the average yield in India is very low. The per capita consumption of potato in India is also extremely low. The yield of potato tuber is usually ten times the weight of the seed-potato sown. The several varieties may be broadly classified into two—*waxy* and *mealy*. The average chemical composition is: starch—18-20%, proteins —2% and oils—0.1%. Potato starch has a variety of uses, among them the preparation of alcohol. Seed-potato is usually sown in September-October, and the crop harvested in February-March when the aerial parts have completely withered. Potato prefers well-drained sandy loam, and thrives under irrigation.

2. **Sweet Potato** (*Batatus edulis*—family *Convolvulaceae*) is an underground tuberous root. There are two common varieties—one with white skin and the

variety sown in September and harvested in March-April yields a larger percentage of oil—40-50% or more. The yield of seeds per hectare varies from 560-1,000 kg. The plant grows well in sandy or clay loam and also in red soil. Castor oil has a variety of uses. It is used as a hair-oil, often perfumed. Purified oil is used as a medicine, particularly as a safe purgative. Raw castor oil is used for burning in villages; it gives a bright light without soot. It is the main ingredient of copal varnish. The oil is also used for lubricating machinery, particularly railway carriage wheels. Its other uses are [illegible]

[illegible] oil is obtained from the dry kernel (copra) of the seed of *Cocos nucifera* (family *Palmaceae*), the yield of oil being about 50%. It is a valuable oil used for cooking, lighting, soap-making and in several toilet preparations. Coconut trees grow luxuriantly along the seacoasts and also further in. A healthy tree bears 60 to 80 coconuts a year, sometimes even 100, fruiting all the year round. Kerala leads in the production of coconuts, coconut oils and coir fibres.

E. **Fruits.** India abounds in some excellent fruits. Apart from their food value they contain one or more vitamins. Although cold storage methods have not been developed extensively yet in our country for the preservation of fruits in fresh condition many of them are available out of the season in the form of various preserves, either as slices or as jams, jellies, pickles, marmalades, CHUTNEYS (hot or sweet), [illegible]

[illegible] is regarded [illegible] and its edible part is the mesocarp. It is a mid-summer fruit (drupe) having over 500 known varieties. The superior ones range in weight from 0.25 to 1 kg. or sometimes even more. Mango is possibly the best dessert fruit, specially noted for its very pleasant taste, pulpy flesh and fine flavour but each variety lasts only for a short time. It makes palatable CHUTNEY, jelly, pickle and tarts. Mango slices and juice are also dried in the sun for off-season use. The keeping quality of ripe mangoes is very poor. They contain vitamins A, C and a little B. Some of the famous varieties are: BOMBAI, LANGRA, GULABKHAS and SEPIA of Bihar; DASHEHRI and SAFEDA of Uttar Pradesh; ALPHONSO of Bombay; FERNANDIX of Goa; BANGA-LORE [illegible]

[illegible] propagated by grafting (see FIG. III/65).

2. **Pineapple** (*Ananas sativus*—family *Bromeliaceae*) is a fruit

(sorosis) with a very delicious taste and flavour. There are several varieties; common good ones weigh 1 to 2 kg. and specially large ones (e.g. Singapore variety) may weigh up to 6 kg., sometimes even more. The plant is a short, stout, perennial herb. It grows in the plains as well as in the low hills, and prefers humus or loamy soil with a little shade, and bears fruits during the rainy season. The plant is propagated by suckers and crowns (see FIG. III/62).

3. **Banana** (*Musa paradisiaca*—family *Musaceae*) is one of the best dessert fruits and is a berry. It is palatable, nutritious, easily digestible and laxative. There are innumerable varieties, each having its own characteristic taste, size and flavour. Bananas are available throughout the year, specially during the rainy season. They are also used for making various sweet preparations. The fruit contains about 20% of sugar (but no starch), about 4.7% of proteins, and vitamins A, B, C and also D and E. It is also rich in K, Ca, Fe and P. The plant is a stout perennial herb and is propagated by suckers.

4 **Orange** (*Citrus reticulata*—family *Rutaceae*) is a winter fruit (hespiridium)—very juicy, tasty and stomachic. The juice contains citric acid and is rich in vitamin C. The plant is a much-branched large shrub. It begins to bear fruits within five years of planting, and a healthy plant, ten years or so old, often bears 300 to 400 fruits, sometimes more, presenting a spectacular sight. The keeping quality of ripe fruits is very poor, and a good quantity sheds and is wasted. Orange plantations thrive at low elevations on the hill-slopes with plenty of lime and phosphate in the soil. Climate is also an important factor. Assam, West Bengal, Madhya Pradesh, Delhi, Punjab, Madras, Coorg and Hyderabad are important centres of orange cultivation in India. There are many species and varieties (see p. 592). Good varieties are commonly propagated by budding (see FIG. III/66) on a hardy variety or by grafting (see FIG. III/64). Oranges are sources of citric acid from the juice, an essential oil from the peel, bergamot oil (a perfume) from the flowers and the peel, and marmalade (a jam) from the skin and pulp of sour varieties.

5. **Pa** [illegible]
(berry). [illegible]
digestive [illegible]
is used as a vegetable; the latex obtained from it contains *papain* which is a digestive enzyme. Fruits, ripe or green, are available throughout the year, particularly during the rainy season. Some good varieties (e g. Ranchi variety) may bear fruits weighing up to 3 to 4 kg., particularly when some of the young green fruits are removed early. Each plant may bear 40 to 60 fruits. The plant is monoecious and, therefore, a few male plants in a plantation help pollination and development of large fruits. Proper manuring and watering are also a prerequisite to this factor. The plant is grown in all warm countries.

F. Sugar. Cane-sugar or sucrose ($C_{12}H_{22}O_{11}$) is the main commercial sugar used universally for sweetening various food preparations. Apart from its taste cane-sugar is one of the best sources of energy available to man. An average acre of sugarcane yields more calories of energy than any other field crop covering the same area. But in India the per capita consumption of sugar is the lowest in the world, being only about 2.7 kg., as against 50.8 kg. in U.K., 51 7 kg. in Australia, and 58 kg. in Denmark. The per capita consumption of GUR (jaggery) in India is about 10 kg. The sugar industry is India's second largest industry next only to textiles. There are two main sources of supply of cane-sugar in the world—sugarcane in tropical countries and sugar-beet in temperate countries, and to a small extent maple (*Acer saccharum*) in the U.S.A In India sugar is also obtained from various sugar-palms, mainly in the form of GUR (jaggery).

1. Sugarcane (*Saccharum officinarum*—family *Graminaceae*) is a tall reed-like grass—2.5 to 4 metres or sometimes more in height. There are several varieties grown all over India. It is cultivated on a large commercial scale in Uttar Pradesh and Bihar, and also Punjab, Madras and Maharashtra. The plant takes 12 to 20 months to mature. It is propagated by stem-cuttings, and the rootstock continues to grow again after this operation. The majority of sugar factories numbering about 179 are located in Uttar Pradesh and Bihar. India is the largest sugar-producing country in the world. Her annual total production of sugar is now about 3 million tonnes. Some improved varieties of sugarcane evolved by the Sugarcane Research Station at Coimbatore are now being cultivated widely in India to feed her numerous sugar mills. Nearly 55% of sugarcanes are used for making GUR (jaggery) and KHANDSARI (unrefined sugar) as cottage industries, while approximately 25% or a little more are used in mills for manufacture of white sugar. A small percentage is used for chewing. Although India is the largest cane-growing country in the world, the varieties of canes commonly grown and their yield are the poorest. The average yield of sugarcanes per hectare per year in India is only 35 to 37 tonnes, which is less than one-fourth of the yield in other good cane-producing countries (Java, Hawaii, etc.). In some States under favourable conditions the yield has gone up to 100 [illegible] se of [illegible] The [illegible] used by *Colletotrichum*, and to the attack of borers. Although sugarcane contains 10-15% of sugar (18-20% in rich canes) with an average of about 13%, the actual recovery of sugar from the cane in Indian sugar mills is only about 10%. On an average 9.5 to 10 tonnes of Indian sugarcane yield one tonne of sugar, whereas in other countries 8 to 9 tonnes yield one tonne. The average production of sugar

in an Indian mill is much less than in other countries (Cuba, Egypt, etc.). Evidently there are many uneconomic sugar mills in India.

Manufacturing Process of Cane-sugar. Sugar is not really manufactured in the mills, but is extracted from the juicy pith of the stem and crystallized in the mills, and refined in the refineries. The process consists of the following stages. (1) **Juice Extraction: Milling.** The cane cut into short lengths by revolving knives is passed through a series of rollers for crushing and releasing the juice It is then strained through perforated metal-sheet strainers to remove *bagasse* (crushed stalks of sugarcane). The juice thus obtained is turbid containing many suspended particles, and is acid (pH 5.1-5.7) in reaction. It is then sent to the boiling house where the extracted juice is first boiled. (2) **Clarification.** Lime (and sometimes also phosphoric acid) is added continuously to the juice in amounts sufficient to raise the pH to 7 or slightly above. The juice is then pumped through high-velocity juice-heaters. Impurities are mostly precipitated, and are removed in 'clarifiers'. The clarified juice is of bright yellow colour. The sediment called *press mud* is used as a fertilizer. (3) **Concentration.** The clarified juice is pumped continuously into a multiple-effect evaporator, where it is concentrated into a clear pale-yellow syrup with soluble solid contents to the extent of 55-64%. It is then boiled in a single-effect vacuum pan and further concentrated. This operation is carried out in batches. (4) **Crystallization.** The semi-solid mass in the pan is called *massecuite*. When the pan is full, the massecuite, still hot, is fed into high-speed centrifuges (1,500-1,800 r.p.m.). The centrifugal baskets have closely woven meshes. When the centrifuge is worked the massecuite is separated into molasses and sugar crystals. The formation of a regular crop of crystals is controlled by an ingenious method. Under centrifugal force the molasses passes out through the meshes and is drained off and collected. The sugar thus obtained is still coated with a thin film of molasses, and is called brown sugar. It has a wide use in confectionery because of its special flavour. To obtain white sugar water is added to the surface of the sugar in the form of a spray while the centrifuge is still revolving. This washes out the brown film, and white sugar is obtained. (5) **Refining.** The sugar thus formed contains 96-97 5% of sucrose. The refineries then take over. The sugar is washed and melted, and mixed with lime when the pH goes up to 10. The melted sugar is saturated with CO_2 and the pH brought down to 7. It is then heated and passed through charcoal filters. 'Continuous rotary pressure filters' are also used for the purpose. The previous process, as described under brown sugar, is repeated and finally the crystals are dried in a rotary drier.

Utilization of By-products. (1) *Bagasse* is mostly used as a fuel, and also used in the manufacture of wrapping paper and cardboard. (2) *Press mud* is used on a limited scale as a manure. A good quality wax obtained from it is used as a shoe polish. (3) *Molasses* has a variety of uses such as manufacture of alcohol, cattle feed, manure, fertilizer, curing tobacco, etc.

2. Sugar-beet (*Beta vulgaris*—family *Chenopodiceae*) is the source of sugar in cold countries (Europe, Russia, Canada and U.S.A.). Sugar is extracted from the fleshy roots which contain 10-20% of sucrose with an average of 13-14%. Russia is the biggest producer of sugar-beet.

G. **Spices.** Spices are certain aromatic and pungent plant products used for

seasoning and flavouring food and various fruit and vegetable preserves. They are used extensively in cookery and confectionery, hot or sweet CHUTNEY, beverages and for chewing alone or with betel leaf. They are also used in medicines. Some of the common ones are as follows. (1) Cardamoms are the seeds of *Elettaria cardamomum* (family *Zingiberaceae*), a perennial herb, cultivated in the Western Ghats, Mysore, the Cardamom Hills of Travancore, and experimentally in the Khasi Hills (Assam). Heavy rainfall and red laterite soil favour their luxuriant growth. India is the largest producer of cardamoms, followed by Ceylon and Indo-China. The fruit has a yellowish skin, and the seeds contain an aromatic volatile oil—usually 4-6%. Seeds form an important spice. The average annual yield is 168-280 kg. per hectare. The greater cardamoms whose fruits have a dark-brown skin and are larger in size come to the market from Darjeeling and Nepal. They are the products of *Amomum subulatum* of the same family. (2) Pepper is the dried berry of pepper vine (*Piper nigrum*—family *Piperaceae*) The dried berry forms commercial black pepper and the seeds form commercial white pepper. Kerala is the principal centre of cultivation. It is also grown in Mysore, Madras, Maharashtra, Bengal and Assam. It is propagated by stem-cuttings. More or less 1 kg. of cured pepper is obtained from each pepper vine. Red pepper or chill [illegible] ...it of *Capsicum frutescens* (family [illegible] or dried fruit. It is grown all over [illegible] is the dried brown or dark-brown [illegible] (family *Lauraceae*). It is grown in Kanara, Mysore, Travancore and Assam in the plains as well as in the hills. Cinnamon oil is also extracted from the bark and the leaf. (4) Bay leaf is the leaf of *Cinnamomum tamala* of the above family. It grows abundantly in the Khasi Hills. (5) Cloves are the dried flower-buds of *Syzygium aromaticum* (family *Myrtaceae*). The green colour of the flower changes to dark-brown on drying. Cloves have extensive uses in curries, preserves and medicines. Clove-oil is extracted from unripe fruits and leaves. Cloves are grown in the Western Ghats and in Kerala but the production is far short of the demand. The main source of supply is Zanzibar, popularly called the 'Island of Cloves', off the east coast of Africa.

[illegible]

[illegible] of them, 2,500 to 3,000 species are in general use in some form or other. The Eastern Himalayas and the Nilgiris are known to be the natural abodes of many such plants. A good number of them are now cultivated in different States on an experimental as well as commercial basis. The Central Drug Research Institute in Lucknow is carrying on research work on indigenous medicinal plants. The Tropical School of Medicine in Calcutta has also done a good amount of work in this direction, and so also some of the big pharmaceutical works. The Medicinal Plants Committee of the Government of West Bengal have already started experimental cultivation of certain very valuable medicinal plants at Rongpo in Darjeeling district with very encouraging results so far. Some of these plants are: ipecac, *Digitalis*, ergot, *Rauwolfia*, *Erythroxylum* (cocaine-yielding), etc. Some rare species of *Podophyllum* (for cancer), *Securinega*

(for poliomyelitis), *Securigera* (for general debility), *Aralia* (for vigour), etc., have also been introduced.

1. Ipecac (*Cephaelis ipecacuanha*—family *Rubiaceae*) is a herb with closely annulated roots, cultivated at Mungpo (Darjeeling) and in the Khasi Hills. The roots are bitter in taste, and contain 3 or 4 alkaloids to the extent of 2-3%, of which *emetine* is the most important one. Formerly powdered ipecac root was used in small doses to treat amoebic dysentery. It stimulates the liver helping secretion of gastric juice but it produces local irritation. Further emetine makes the heart weak and slow, and lowers the blood pressure. Now emetine hydrochloride is injected for the treatment of amoebic dysentery. Emetine is a highly poisonous drug.

2. Rauwolfia (*Rauwolfia serpentina*—family *Apocynaceae*) is an evergreen undershrub found extensively in the tropical Himalayas, all over Assam and the Western Ghats. The dried root of this plant contains five alkaloids to the extent of 0.5%. Of these *serpentine*, *serpentinine* and *rauwolfine* are most powerful. Rauwolfia drug has extensive uses all over the world for its hypnotic and sedative properties and is used in the treatment of mental imbalance and insanity. It has also the property of reducing high blood pressure.

3. Nux-vomica (*Strychnos nux-vomica*—family *Loganiaceae*) is a very valuable drug. The plant is a handsome tree growing almost throughout tropical India, specially in Deccan and West Coast. The seeds, intensely bitter in taste and extremely poisonous, contain a very important alkaloid *strychnine* (and also another alkaloid *brucine*) to the extent of 0.5-1.2%. Strychnine is an effective stomachic, a tonic and a stimulant in of course very minute doses. It increases the secretion of gastric juices, sharpens the appetite and promotes digestion. It helps peristaltic movement of the intestines. It is also used in the treatment of nervous disorders. It increases mental alertness, field of vision and capacity for muscular work. It is also effective in the treatment of paralysis.

4. Cinchona is the famous quinine-yielding plant. The bark of a plant (unknown for a long time) was in use as a febrifuge in South America till the late 19th century. The plant yielding this bark was discovered in Peru as late as 1739 by La Condamine, and in 1742 Linnaeus named it *Cinchona* after the Countess of Chinchon, wife of a Spanish Viceroy of Peru, who was cured of an attack of malarial fever by the bark in 1638. Thereafter the Jesuits popularized its use. From then on it was popularly known as 'Countess bark' or 'Jesuit's

[illegible]

and a quantity of seeds. The small stock that could stand the journey was sent to Kew Gardens, London in 1861; some seeds were brought

to India. In the meantime Dr Anderson, the then Superintendent of the Royal Botanical Gardens, Calcutta, was sent to Java and he brought back with him 412 plants and a quantity of seeds. The whole lot was sent to Ootacamund in the Nilgiri Hills in 1861 where the plants showed luxuriant growth. He brought 193 plants from Ootacamund to Calcutta in 1862 but the plantation did not prove to be a success in the plains; so the whole stock was removed to Darjeeling district where finally the plantation was established in 1864. Dr Anderson unfortunately died of malarial fever, and the work was entrusted to his successor Dr King who made the plantation and the manufacture of quinine a commercial success.

Species. Of about 40 species of *Cinchona* (family *Rubiaceae*) the quinine-yielding ones commonly cultivated are *C. ledgeriana* (yellow bark), *C. officinalis* (brown bark), *C. succirubra* (red bark) and several varieties and hybrids. Cinchona plants are low trees (6-15 metres high) and prefer a cool climate and well-drained soil, as in hill-slopes.

Collection of Bark. There are various methods of harvesting the bark—thinning of plantation, uprooting, lopping of branches, coppicing and shaving. Quinine and other alkaloids are formed richly in the bark of the root and the stem in the region 30 cm. below and above the ground, more in the former than in the latter, gradually decreasing and disappearing downward and upward. The bark is stripped off and dried in the sun or in a drying shed during the rainy season.

Chemistry of Bark. It was in 1820 that quinine was first extracted. About the middle of the century several alkaloids, particularly quinine, quinidine, cinchonine, cinchonidine and an amorphous alkaloid, were recognized in the bark. In 1888 a quantity of about 136 kg. of quinine was manufactured for the first time. Prior to this a crude preparation of the bark powder was used under the name 'cinchona febrifuge'. Java bark is richest in alkaloid contents, and over 90% of the world output comes from Java plantations. Bengal bark and Madras bark are rather poor in this respect. An analysis of Bengal bark gives the following figures:

	Quinine	Other alkaloids	Quinine sulphate
C. ledgeriana	5.49%	2.03%	7.38%
C. officinalis	2.77%	2.62%	3.72%
C. succirubra	1.92%	4.13%	2.75%

All the bark collected in India used to be shipped to Europe for extraction of quinine, and the manufactured product imported into this country. About the year 1875 two factories were established in India—one at Mungpo in the Darjeeling district and another at Naduvattam in the Nilgiris.

Manufacture of Quinine. (1) Grinding. This is done by a disintegrator (a heavy

circular iron casing) fitted with heavy iron bars which are made to spin with a tremendous force—2,500 revolutions per minute. The powdered bark is then strained through a fine piece of silk in contact with a spirally wound brush. (2) **Extraction.** 136-227 kg. of powdered bark are put into each of the several rows of cylindrical iron vats, called *digestors*, fitted with a spirally-coiled steam-pipe, an oil-pipe and a water-pipe, and a mechanical stirrer. To each vat is added about 900 litres of 20% caustic soda. After continued stirring and heating for about 3½ hours, the oil released is seen to float taking up all the alkaloids, and is then skimmed off. To the alkaloid-bearing oil dilute sulphuric acid is added and the mixture agitated by jets of steam. This treatment induces the oil to give up the alkaloids to the acid solution. (3) **Purification.** The acid liquor is neutralized with caustic soda solution, and poured into long troughs where the quinine sulphate partially crystallizes out in two days' time as dirty-looking greyish pulp. This is poured into centrifugal separator which is a cylindrical copper-gauze basket lined with a piece of calico. The basket is made to revolve at a speed of 1,200 revolutions per minute. All the liquid is strained out. A greyish cake of crystals is left in the basket as crude quinine sulphate with about 10% of other alkaloids. This is dissolved in boiling water A precipitate settles down and the supernatant liquor now contains practically pure quinine sulphate. It is collected, and finally crystallized. The crystals are dried in a drying room. The precipitate forms 'cinchona febrifuge' which nowadays is not much in demand.

5. **Aconite** (*Aconitum*—family *Ranunculaceae*). *Aconitum napellus* is the European aconite, while *A. ferox* is the Indian aconite. *Aconitum ferox* is an erect perennial herb growing wild in the sub-alpine Himalayas. The plant is highly poisonous. Its tuberous roots contain a few alkaloids, of which *aconitine* is the chief active one. Aconite relieves pain due to sciatica, neuralgia, rheumatism and inflamed joints. Aconite is used as a tonic, febrifuge, antiperiodic and sedative. It is a highly poisonous drug.

6. **Deadly Nightshade** (*Atropa belladonna*—family *Solanaceae*) is a short erect herb growing wild in the temperate Western Himalayas. It is also cultivated as a medicinal plant. The leaves are collected when the plant is in the flowering stage, and dried. The dried leaves contain *atropine* and two other alkaloids to the extent of 0.3%. All parts of the plant, however, are narcotic and poisonous. Atropine is the basis of the drug *belladonna* which is used to relieve pain in neuralgia and inflammation of muscles, palpitation of the heart and pain of the cardiac muscles, and has proved to be very useful in spasms due to bronchitis, asthma and whooping cough, and in spasms of the involuntary muscles. Atropine gives great relief in all such cases. Atropine is an excellent remedy for night sweats, as in pthisis, and is an antidote in certain types of poisoning. Atropine is used to dilate the pupil of the eye and thus to facilitate its examination.

7. **Poppy** (*Papaver somniferum*—family *Papaveraceae*) grows wild in the Himalayas, and is also cultivated in Bihar and Uttar Pradesh under official control. It yields a narcotic drug which is the latex

obtained by incising unripe capsules. The latex is dried and made into balls or flattened masses which form the commercial *opium*. Opium contains about 9.5% of *morphine* and also a number of other alkaloids. Opium and morphine relieve pain and induce sleep. Opium relieves intestinal pain and cures diarrhoea and dysentery but it lessens appetite and retards digestion. It removes the sensation of hunger, coughing, fatigue, etc. In large doses the central nervous system becomes depressed. Opium is sedative, astringent and anodyne. The action of morphine is always more definite and less harmful than opium. The use of opium in regulated doses is regarded as a panacea for all physical ailments in old age

[illegible] rs [illegible] *a* and several hybrids of the family *Theaceae*. Tea is now a universal drink. But from the tea garden to the tea cup there is a long history. Tea plants are kept bushy by regular pruning and they continue to grow for 60 years or even up to 100 years. If left to themselves they grow to the size of small trees.

A Short History. The plant growing wild and uncultivated was first discovered in North East Assam by Charles Alexander Bruce, an army man, in 1826. He collected seeds and plants and sent them to the Royal (now Indian) Botanical Gardens near Calcutta. They were grown with success and found to be real tea plants although distinct from the Chinese species A Tea Committee was appointed by Lord Bentinck in 1834 to enquire into the possibility of profitable cultivation of tea plants in India. The Committee considered the discovery of tea plants in Assam of far-reaching importance, and strongly recommended their cultivation in Assam and also elsewhere in India, particularly because [illegible]

this time tea cultivation became established in Assam, North Bengal and South India (Kerala, Mysore and Nilgiri Hills). By 1874 there were 11,680 acres of land under tea cultivation In 1881 the Indian Tea Association was formed in Calcutta, which later in 1911 had its headquarters at Tocklai Experimental Station at Jorhat (Assam) for better facilities of research work on various aspects of the culture and manufacture of tea. India is now the foremost tea-growing country with about 6,500 tea gardens. In 1961 she produced record crops of tea totalling 353.5 million kilograms (in 1962 it was 344 million kg), the world output in the same year being 752 million kg. Roughly half of India's total output is proproduced in Upper Assam. India is now aiming to produce over 400 million kg. in the near future. The internal consumption of tea has now gone well over 140 million kg. Foreign earnings from tea exports amounted to Rs 124 6 crores

for 205 million kg. of tea exported during 1961 constituting about 18% of the total value of India's exports, and Rs 124.9 crores for 214 million kg. exported during 1962. It may be of interest to note that Britons drink one-third of the world's tea production with 2,000 cups each a year, the Irish coming next with 1,600 cups each a year.

Tea Leaves. There are different grades of manufactured tea. The terminal bud with *two* leaves just next to it forms *fine* tea; the same with *three* leaves forms *medium* tea; and the same with *four* leaves forms *coarse* tea. The average yield of manufactured tea varies usually from 450 to 1,120 kg. per hectare per year, and 1.8 kg. of green leaves usually make 0.45 kg. of cured tea. The yield of green leaves per plant is more or less 0.9 kg. Tea plants grow in the plains and in the hills to an altitude of over 1,800 metres—better tea always at a high elevation—and flourish in localities with abundant rainfall. Annual pruning after plucking (and the same operation even after the second year of planting) is a very important practice helping the plant to 'flush' profusely. Regular picking of leaves begins from the third year or the fourth year, and continues for 30 years or more. Tea bushes require proper irrigation and adequate manuring for increased yield. Chemical fertilizer like sulphate of ammonia at the rate of 110 kg. per hectare, green manure (growing certain leguminous plants like *Tephrosia*, *Derris*, *Sesbania*, *Cajanus*, etc.), cattle manure and leaf compost are very beneficial to them.

Chemistry of Tea. Manufactured tea contains 4-5% of tannins (catechins) which are responsible for colour and strength of the infusion, 3.3-4.7% of caffeine which is a stimulant for the heart, a little volatile oil to which the aroma of the tea is due, about 8% of resinous matter which gives the reddish-brown colour to tea infusion, etc. Green tea leaves contain 13-18% of tannins but greater portions of them are converted into sugar and gallic acid during the process of manufacture. Starch is also converted into sugar during the same process. Caffeine distribution in tea leaves is as follows: 1st leaf and bud—4.7%, 2nd leaf—4.5%, 3rd leaf—3.7%, 4th leaf—3.3%. Caffeine contents are not changed during the process of manufacture. Investigations are now being carried on at Tocklai Experimental Station at Jorhat (Assam) for the recovery of caffeine and tannin chemically from the huge quantity of tea waste accumulating every year.

Manufacturing Process. (1) *Plucking.* The quality of cured tea depends to a great extent on the standard of plucking, the proportion of desirable constituents gradually diminishing from the bud to the lower leaves. (2) *Withering.* After weighing the leaves are taken to the withering house and spread out thinly on bamboo racks for about 18 hours (by employing heated air it has been possible to reduce the period to 2 to 3 hours). (3) *Rolling.* The withered leaves, sufficiently flaccid in the previous process, are passed through the rolling machine for half an hour. Rolling imparts twists to the leaves. Major chemical changes also take place in this process, and fermentation begins here. (4) *Sifting.* After the first

rolling the sifting is done. Finer meal is taken to the fermentation room, while a second rolling is done with the coarser portion. (5) **Fermentation.** Sifted leaves are then spread on the floor of the fermentation room where the temperature is maintained at more or less 27°C. for 3 or 4 hours. During fermentation (actually enzymic oxidation, not bacterial) the flavour and colour develop. (6) **Firing.** This takes place usually in two stages—the first one at 93°C. and the second one at 82°C. Firing reduces moisture contents to 3-4%, thus ensuring better keeping quality. Firing also arrests further process of fermentation, and in this process the quality of tea further improves. This is *black tea*. In the preparation of *green tea* (largely used in China and Japan) only rolling and drying are practised; other processes are altogether omitted. (7) **Sorting and Grading.** The fired tea is then sorted into grades by automatic devices. Finally it is packed into plywood chests (specially made for the purpose) for marketing.

2. **Coffee.** Coffee is a favourite drink in South India. Seeds of *Coffea arabica* and *C. robusta* (family *Rubiaceae*), particularly the former, are the sources of coffee. The seeds are roasted to a desired brown colour and then powdered. The aroma of coffee powder develops on proper and skilful roasting. Certain chemicals are also added for this purpose. A coffee bush usually yields 0.45-0.9 kg. of cured coffee. Coffee contains several vitamins and also caffeine. Main coffee plantations are in the low hills of South India—Mysore, Madras, Coorg, Travancore and Cochin. It is also cultivated in Orissa. The coffee plant, a native of Abyssinia, was first introduced into India by a Muslim pilgrim more than 250 years ago. Brazil and Kenya are the world's largest suppliers of coffee

3. **Cocoa.** Cocoa makes a refreshing and nourishing drink. It is prepared from the seeds of *Theobroma cacao* (family *Sterculiaceae*), a native of tropical America. It is a small tree cultivated more or less extensively in tropical America, West Indies, Brazil, Ghana and Kenya. The world's supply comes mainly from Brazil, Kenya and Ghana (Ghana supplying the largest quantity). Cocoa is also cultivated in Java and Ceylon. Each tree bears commonly 70 to 80 fruits, each measuring 15-22×7-10 cm. and bearing numerous seeds. Fruits are cut or broken open, and the seeds dried, roasted and powdered. In addition to its use as a drink cocoa powder is used in the making of chocolate with certain ingredients mixed with it. On an average 50 pods each having about 30 good seeds, yield over 1 kg. of cured cocoa. Cocoa-butter is used in medicine.

J. **Timber Trees.** Timber is the wood (heartwood) used for various building purposes: houses, boats, bridges, ships, etc.; for making furniture, packing boxes, matchsticks and boxes; for making plywood tea chests, flush doors, commercial boards, etc.; and for railway sleepers. In addition, wood chips and shavings are used for making compressed wood which is in demand for panelled doors, table tops, room partitions, hard blocks, etc. Timber and firewood (fuel) together with many useful forest products constitute the forest

wealth of a country. To be self-sufficient in them a country should normally have about one-third of the total land area under forests. In this respect India having only 22.2% lags behind other countries. In India Madhya Pradesh has now the largest forest area, while Assam occupies the second place. The timber trees of Indian forests number over 75 species. The quality of timber depends on its hardness, strength, weight, presence of natural preservatives like tannin, resin, etc., durability against heat, moisture and insect attack, workability, grains, colour, porosity and capacity to take polish and varnish.

1. **Teak** (*Tectona grandis*—family *Verbenaceae*) is the famous timber of the Deccan Plateau, Madras, Kerala, Maharashtra, Bihar and Orissa. The tree is about 36 metres in height. It is also being successfully grown in Assam. Teak yields a very valuable timber with straight grains and light golden-brown colour. The wood is hard, strong, moderately heavy (720 kg. per cu. m.) and extremely durable, being immune to insect and fungal attacks. It does not warp, shrink or expand. This timber is used for making handsome furniture of various designs. It is also used extensively for doors, windows, beams, rafters, etc. It is, however, a very costly wood. Burma teak is the best. The Deccan Plateau produces the best Indian teak.

2. **Indian Redwood** (*Dalbergia sissoo*—family *Papilionaceae*) is a tree of sub-Himalayan forests extending from Assam to Punjab. It is a very valuable timber with fine to medium grains and golden brown to dark brown colour. It is hard (harder than teak), strong, very durable and moderately heavy (800-850 kg. per cu. m.). It makes handsome furniture. It is easy to work and takes a good polish, and is least susceptible to white ants and borers. The timber is also used for posts, rafters and boards. It makes durable carts, coaches and boats. The wood is widely used for carving.

3. SAL (*Shorea robusta*—family *Dipterocarpaceae*) is a very valuable timber tree, growing to a height of 20-25 metres, sometimes 30 metres or even more. The SAL tract stretches along the sub-Himalayan region from Assam to Punjab. Tracts of SAL also occur in Madhya Pradesh, Bihar, Orissa and Andhra. The timber is very hard, strong, heavy (900 kg. per cu. m.) and very durable even under water. It is used extensively for railway sleepers and for house-building as posts, rafters, planks, door-frames, etc., and for construction of bridges and piles. It is also used for hubs of wheels and bottoms of carts and carriages. It stands heat and water well. *Shorea assamica* of Upper Assam and Nagaland is not very durable as a railway sleeper but it has a variety of other uses. It is suitable for doors, windows, planking and tea chests, and makes good plywood.

4. JARUL (*Lagerstroemia flos-reginae*—family *Lythraceae*) is a good timber tree common throughout India, particularly Assam and West Coast. It grows mainly along banks of rivers and is also cultivated

for its ornamental mauve-purple flowers. The timber is hard, durable (even under water), straight-grained, and takes a good polish. The wood is light to moderately heavy (640 kg. per cu. m.) and pale red. It is used for house-building, boat-building, furniture and cart-making, posts, bridge-piles and bridges. It is also good for general uses.

5. Mahogany (*Swietenia mahagoni*—family *Meliaceae*) is an evergreen tall tree (18-21 metres high, sometimes even 30 metres). It is a valuable timber tree. Mahogany is an indigenous tree of Central America. In India it is sporadically grown in gardens, along roads and in forests. The wood is very hard and durable, coarse-grained and takes a good polish. It is dark reddish-brown in colour, and is used for making furniture, boats, ships, caskets and the body of some musical instruments.

6. Pines (*Pinus longifolia* and *P. khasya*—family *Abietaceae*) are evergreen, tall, straight, coniferous trees. They attain a height of 30-45 metres, and grow abundantly and gregariously at an altitude of 900 to 1,900 metres or even higher. *Pinus khasya* grows in the Khasi Hills and *P. longifolia* in the Western Himalayas. The wood is light (530-610 kg. per cu. m.), moderately hard, easy to work, white to pale brown in colour, with straight but uneven grains, numerous dark-coloured resin-ducts and large knots, and odorous. It seasons well and takes a fairly good polish, and is durable if not exposed. It is used extensively in the hills for house-building and rough types of furniture-making, and for packing cases.

7. Deodar (*Cedrus deodara*—family *Abietaceae*) is an evergreen, elegant-looking, cone-shaped, coniferous tree attaining a height of 30-60 metres. It grows at an altitude of 1,800 to 2,500 metres. It is a well-known timber tree of the Western Himalayas and grows plentifully in Kashmir. The wood is light (560 kg. per cu. m.), moderately hard, extremely durable and seasons well. It is yellowish-brown in colour and odorous. It is easy to work and finishes well but is not suitable for fine work because of continuous oozing of resin. This timber is used for sleepers after proper treatment, for house-building as beams, rafters and flooring, bridges and light furniture. It is almost immune to white ants. The wood is a source of deodar oil.

Some Common and Useful Timber Trees of Assam. In addition to SAL, AJAR or JARUL, SISSOO, teak, pine and deodar, as described above, the following may be mentioned: (1) BONSUM (*Phoebe attenuata* and *P. goalparensis*—family *Lauraceae*) [illegible] planks, doors and

[illegible]

ture; (5) AMARI (*Amoora wallichii*—family *Meliaceae*)—wood hard, used for furniture, doors and windows; (6) LALI (*Dysoxylum procerum*—family *Meliaceae*)

—wood bright red, moderately hard, much used for doors and windows: (7) GONSOROI (*Cinnamomum glanduliferum*—family *Lauraceae*)—wood soft but durable, scented, it makes fairly strong furniture, cupboards and boxes and is somewhat better than POMA; (8) KHOKAN (*Duabanga sonneratioides*—family *Lythraceae*) —wood soft, used for cheap furniture, suitable for plywood; (9) TITA-SOPA or CHAMPA (*Michelia champaca*—family *Magnoliaceae*)—wood light but durable, mainly used for furniture; (10) NAHOR (*Mesua ferrea*—family *Guttiferae*)—wood very hard and heavy, used for posts, beams, bridge-piles and railway sleepers.

K. **Fibres.** Fibres are threadlike tissues obtained from different parts of the plant body. They are mostly made of sclerenchymatous cells, strongly lignified and thickened. Cotton fibres are, however, made of cellulose. Commercial vegetable fibres may be classified as (*a*) floss fibres or lint which are the hairy outgrowths of the seed, e.g. cotton, silk-cotton and madar; (*b*) bast fibres which are the sclerenchymatous tissues of the secondary phloem or bast, e.g. jute, hemp and ramie; (*c*) coir fibres which are the fibrous husk of coconut fruits; and (*d*) leaf fibres which are the sclerenchymatous tissues of the leaf, e.g. bowstring hemp and aloe (*Agave*). The quality of fibres depends on their length, strength, fineness, lustre, reaction to high temperature and water, etc. Some of the important commercial fibres are as follows.

1. **Cotton** (*Gossypium sp.*; see p. 568; family *Malvaceae*) is the most important commercial textile fibre, spun into yarn and woven into various kinds of garments, screens, sheets, canopies, sails and a variety of other things. Cotton thread is used universally for sewing and stitching. The quality of cotton fibres is judged by their length, strength, fineness and silkiness. Indian cottons are poor in respect of length, having a short staple—12.7-25.4 mm.; *G. indicum* and Upland American cotton (*G. hirsutum*) have a lint length of 25.4 mm.; while Egyptian cottons 31.7-38 mm. and American cottons 38-50.8 mm. Upland American cotton, naturalized in India, is extensively cultivated in India. Of all Indian cottons Broach cotton of Gujarat is the finest. The cultivation of long-staple foreign cottons has not proved to be a success in India. Although the total area under cotton in India is the largest in the world her total output is far below that of other cotton-producing countries The average annual yield of cotton lint (and not seed cotton) in India is only about 97 kg. per hectare; while in U.S.A. it is 177 kg., in Japan 203 kg, in Egypt 416 kg., and in U.S.S.R. about 272 kg. Of the total output of cotton in India long-staple cotton comprises only about 7%. Thus there is ample scope for improvement of cotton in India. Gujarat, Maharashtra, Punjab, Madhya Pradesh, Mysore, Madras, Andhra, Rajasthan and Uttar Pradesh are the important cotton-growing areas in India. Black soil is most suitable for cotton cultivation.

2 **Jute** (*Corchorus capsularis* and *C. olitorius*—family *Tiliaceae*) is a very valuable bast fibre obtained almost exclusively from the above

two species. Jute is cultivated widely in the low-lying areas of Assam, West Bengal and Tripura, and to some extent only in Bihar, Orissa and Uttar Pradesh. Of late, the production of jute in Assam has increased immensely so much so that it has now taken a leading position. The plant thrives under conditions of plenty of rain and flooding at a later stage. The sowing season is March or a little later, and the harvesting season is July-September Fibres mature with the ripening of fruits. After harvesting the jute plants are retted in water for 10 to 15 days, sometimes more, and then the fibres are stripped off the stalks by hand. The fibres are then washed, dried in the sun and finally baled. The annual yield in India usually varies from 823 to 1,646 kg. per hectare. The total yield, however, is far short of her requirements. Of late with the extension of cultivation the annual jute production has gone over 5.8 million bales. Jute fibres are used extensively for making gunny bags, cheap rugs, carpets, cordage, hessian (coarse cloth), etc., but they are much less strong than hemp.

3. **Hemp** obtained from GANJA plant (*Cannabis sativa*—family *Cannabinaceae*) is the true hemp. But this is an excisable plant and its cultivation is restricted. Commercial hemp is the sunn-hemp or Indian or Bombay hemp (*Crotalaria juncea*—family *Papilionaceae*). Sunn-hemp yields very strong fibres used for various kinds of cordage—ropes, twine, etc., coarse sheets, tents, screens and fishing nets. Sunn-hemp is much stronger than jute and stands water well. It is also used for making strong paper. It is cultivated on a large scale in Uttar Pradesh and also in Bihar and Central India. Elsewhere it is cultivated as a green manure crop. It is a monsoon crop requiring about four months to mature and is harvested in August-September before pod-formation when the plants usually grow to a height of about 2.5 metres. The plants are cut or pulled up and steeped in water for a week or so for complete retting. Fibres are then pulled out in [illegible]

[illegible]

hectare per year.

4. **Coir** is the husk fibre obtained from dry fruits of coconut (*Cocos nucifera*—family *Palmaceae*). The fibres are used for making door mats, mattings (to cover floors), mattresses, carpets, rugs, etc. They are also used for making coarse brushes, cords and ropes, and also for stuffing sofas and carriage seats. Kerala leads in the production of coconuts and in the manufacture of coir goods. Kerala is only second to the Philippines in this respect. Kerala contributes the maximum quantity for export to foreign countries. Other States like Mysore, Madras, Andhra, Orissa and Maharashtra have also developed this industry. The annual production of coir fibres in India is estimated to be 1,30,000 tonnes.

L. Rubber is obtained from the latex of *Hevea brasiliensis* (family *Euphorbiaceae*), a big tree, which is the main source of commercial rubber. The tree comes into production 7 or 8 years after planting; maximum production is usually obtained in about the 15th year. The latex is collected by tapping the bark. It is then allowed to coagulate with the addition of water and a little acetic acid. The coagulated mass (rubber) is then separated from the liquid portion, washed and dried in the smoke-house. It is then passed through rollers and pressed into blocks, sheets, crepe, etc. The use of rubber as tyres and tubes on the wheels of of various types of vehicles, crepe soles, rubber shoes, rubber sheets, rubber tubings, beltings, and various other goods of commercial importance, is of course well known. Indian rubber is mostly consumed internally in the country. The majority of rubber plantations are in Travancore; the rest are in Cochin, Madras and Coorg. Kerala accounts for over 90% of the total Indian output. The supply, however, is still far short of the internal demand. The average yield of rubber in India is rather low, being only about 336 kg. per hectare per year. The rubber obtained from *Hevea brasiliensis* is called **para-rubber** that from *Manihot glaziovii* **ceara-rubber**, that from *Castilloa elastica* **Panama-rubber**, that from *Ficus elastica* **India-rubber**, etc. Synthetic rubber is gradually coming into use.

M. Paper. The importance of paper for various essential purposes cannot be overestimated. Printing paper, writing paper, newsprint, wrapping paper, cardboard, poster paper, etc., are some of the items requiring an enormous quantity of different grades of paper. In India the total production of paper in various Indian paper mills cannot, however, meet her demand. Paper mills and pulp mills may be separate or both may be integrated.

An Early History. More than 5,000 years ago the Egyptians first produced a kind of paper from paper-reed (*Cyperus papyrus*—family *Cyperaceae*), a river-side plant abundant on the banks of the Nile. The stem of this plant split into thin strips was pressed into stiff sheets which were then used as a writing material. Much later, about 2,000 years ago, in Asia Minor animal skins were specially treated to make a sort of writing paper (parchment paper). Possibly about this time the Chinese began to make paper by boiling rags and stems into pulp and finally beating it into sheets. This was the beginning of manufacture of the modern type of paper. About 1,000 years ago the Arabs got the secret of paper-making from some Chinese paper-makers, and founded a paper mill at Baghdad. A few hundred years later (by the end of the 15th century) the art of paper-making spread to Europe. In ancient India the foliated bark of BHURJIAPATRA (*Betula utilis*—family *Betulaceae*) which is easily separable into thin large white sheets was used as a writing material The plant grows at an altitude of 3,350-3,960 metres both in the Western and the Eastern Himalayas. The first paper mill was established in India in the year 1820 (see p. 689).

Raw Material. Cellulose is the basic constituent of paper, and the various raw materials used for paper pulp are: wood of coniferous and other trees, different kinds of bamboo (*Bambusa*, *Melocanna*, *Dendrocalamus*, etc.), various grasses such as saboi (*Ischaemum*), *Imperata*, *Erianthus*, *Phragmites*, etc. In addition, waste paper, cotton and linen rags, straws, etc., are also used extensively. Bagasse (see

p. 676) is also used widely. Fir and spruce of the Himalayas are considered very suitable for quality newsprint. Lignin and other non-cellulose components of raw materials are removed by cooking and bleaching. Finally it is the cellulose that makes paper.

Paper Mills and Production. In India the first paper mill was started at Serampore by Dr William Carey, a missionary, in the year 1820 but this venture ended in failure. Between 1867 and 1891 three paper mills were started in West Bengal, one in Lucknow, and one in Poona. It is, however, from 1925 that the industry has been steadily growing. Since World War II it has made considerable progress. India is still not self-sufficient in this most urgent commodity with her annual production of over 210,000 tonnes in 20 paper mills. The position of newsprint is much worse with the production of about 23,000 tonnes a year (or about 63 tonnes daily) by the only mill in India at Nepanagar in Madhya Pradesh, while the country's minimum requirement at present is more than 119,000

exclusive production of newsprint. It may be noted that the average per capita consumption of paper in India is only about 0.64 kg., while it is 68 kg. in the United Kingdom, 79 kg in Canada, and over 136 kg. in U.S.A.

Pulp Making. Raw material cut into small chips is passed through a series of screens of various meshes to obtain uniformity of size. It is then cooked in a huge quantity of water. For chemical pulp required for different grades of

it to get white paper, usually with hypochlorites, liquid chlorine, milk of lime, sodium peroxide, etc., are important processes. Rags and waste papers, when used, are first boiled with lime and caustic soda. Different grades of paper are finally made according to choice and need by mixtures of different pulps in particular proportions. Different chemicals such as rosin, paraffin, wax, alum, sodium aluminate, etc., are used to give the paper a particular finish and to make it non-absorbent to liquids. The pulp is concentrated to 70% solids or even more before sending it to the mill.

Paper Making. The dewatered pulp is passed through a series of roll-type presses. At the outgoing end the sheet is passed through 'driers' in the form of heated cylinders. The dried sheet is then passed through highly polished rolls

called 'fillers' are used. The forward-moving sheet which is continuous is wound into large rolls, and finally cut into sizes.

PART X *Palaeobotany*

Chapter 1 GENERAL DESCRIPTION

Palaeobotany deals with the study of fossil plants preserved in rocks of various geological periods. A *fossil* (*fossilis*, dug out) *is any relic* or trace of past life (plant or animal) preserved in the earth's crust during its formation in different ages and periods. The term was formerly used to refer to anything dug out of the earth, but is now used to designate any tangible evidence of former life embedded in the earth and preserved in some form or other. During the period between the cooling of the earth and the present day the earth's crust has experienced several revolutions involving widespread changes in its topography, *viz.* redistribution of land and water, elevation of submerged land, submergence of elevated land, sedimentation of fragmentary materials and organic remains at the bottom of lakes and oceans, etc. The sediments gradually became transformed into rocks (sedimentary rocks) with plant and animal remains in them preserved in the form of fossils. These sedimentary rocks have been divided into different geological periods on the basis of their fossil contents (see table at p. 696). Only certain parts of plants are resistant to decay, and these, when properly buried in muds and sands, become transformed into fossils in consolidated sediments such as shales and sandstones. Pteridophytes and gymnosperms have been found in large numbers in a fossil state, while bryophytes, algae and fungi having delicate parts are seldom encountered as fossils. Fossils of both plants and animals not only give us a glimpse of ancient life occurring many millions of years ago but also help us to trace the course of evolution.

Formation of Fossils. Two major factors are involved in the mode of preservation of plant and animal bodies in the form of fossils: rapidity of burial and prevention of normal decay. A combination of these two factors frequently occurs such as burial in stagnant water, complete burial under fine-grained sediment, or rapid infiltration of mineral substances into the cell-walls, in any of which the quantity of available oxygen is diminished.

Kinds of Fossil Plants. (1) Petrifaction (*petra*, rock; *facere*, to make). This means fossilization by cell to cell replacement of certain plant parts by a good number of mineral substances, of which carbonates of calcium and magnesium, iron sulphide, and silica are most common. Petrified fossils have shown the external form, internal structure, and sometimes substance of the original plant, often in great

detail. It happened that before vertical pressure came into play, plant fragments became saturated with water containing mineral substances in solution. The mineral substances infiltrated into the plant body, and gradually separated out from the solution. In due course the water was also expelled. Finally the tissues and cells had a complete filling of solid material, and the whole formed a solid, incompressible, hard mass. Coal balls and silicified wood are the best examples of petrifaction. Coal balls remain embedded in the coal and are of varying sizes, usually about the size of potatoes. They are often very rich in calcified remains of plant materials. Silicified stumps of wood have often been so well preserved that it has been possible to prepare thin sections of them for microscopic examination. They often reveal minute structures in extraordinary detail. (2) **Incrustation or Cast.** This is a fossil with the external form as a cast. The internal structure is not preserved. Here the plant substances have disappeared and a cavity has been left; this cavity is subsequently filled up with mineral matter which thus forms a *cast* of the original plant. The surrounding material, the mould, forms the *incrustation*. Casts of pith cavities of hollow stems are sometimes found which have resulted from the entry of fine sand or mud into the hollow stems. In course of time the filling material is converted into an internal mould of the hollow stem, e.g. the pith cast of *Calamites*. (3) **Compression.** The external form of the plant is modified by vertical pressure of the sediment in which the plant material lies embedded. When a plant is subjected to compression, some of its parts—leaves, seeds, fruits, trunks, etc., leave impressions on the rock surface. The compression shows the outline of parts of plants. (4) **Compactions.** These are plants or plant fragments compressed by vertical pressure. Masses of plant fragments without intervening matrix such as are found in peat and coal are large scale compactions. (5) **Impressions.** The forms impressed on a matrix, as on coal and shale, are usually termed impressions.

Chapter 2 FOSSIL PLANTS

CLASSIFICATION OF FOSSIL PTERIDOPHYTES AND GYMNOSPERMS

Pteridophytes. (A) Psilopsida (or Psilophytinae). **Order 1.** Psilophytales, e.g. *Psilophyton*. (B) Lycopsida (or Lycopodiinae). **Order 2.** Lepidodendrales, e.g. *Lepidodendron*, *Sigillaria*, etc. (C) Sphenopsida (or Equisetinae). **Order 3.** Hyeniales, e.g.

Hyenia, Calamophyton, etc. **Order 4.** Sphenophyllales, e.g. *Sphenophyllum*. **Order 5.** Equisetales, e.g. *Equisetites*. **Order 6.** Calamitales, e.g. *Calamites*. (D) Filicinae. **Order 7.** Coenopteridales, e.g. *Etapteris* and *Botryopteris*. **Order 8.** Marattiales, e.g. *Danaeopsis, Marattia*, and also some other orders.

Gymnosperms. Order 1. Cycadofilicales (or pteridosperms), e.g. *Glossopteris, Lyginopteris*, etc. **Order 2.** Cordaitales, e.g. *Cordaites*, **Order 3.** Bennettitales (Cycadeoidales), e.g. *Williamsonia, Cycadeoidea*, etc. **Order 4.** Ginkgoales, e g. *Baiera* and *Ginkgo* (fossil and living). **Order 5.** Cycadales, e.g. cycads (living and fossil) **Order 6.** Coniferales, e.g. conifers (living and fossil) such as *Araucaria*, pine, juniper, cypress, yew, etc ; *Elatocladus* and some other genera are found as fossils only.

[Note that Cycadofilicales, Bennettitales and Cycadales resemble one another

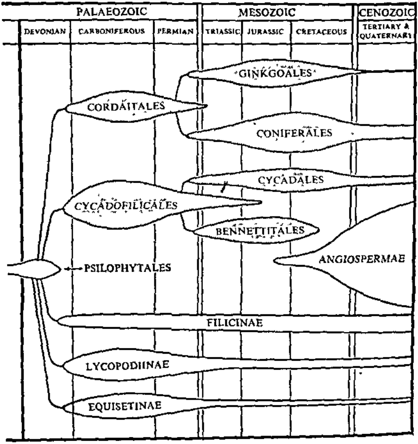


FIG. 1. Diagram showing possible origin, evolution and distribution of pteridophytes, gymnosperms and angiosperms in different geological periods For time scale see table at p. 696.

in respect of their ovule structure and certain other characteristics, and are together called Cycadophyta. These 3 orders also resemble ferns in many respects.]

Palaeozoic. The flora of this age, particularly of the Carboniferous period, is predominantly characterized by giant lycopods and horsetails, and abundance of ferns (Coenopteridales, etc.), mostly small in size. So the Palaeozoic is called the 'age of pteridophytes' The primitive gymnosperms (Cycadofilicales and Cordaitales) made their appearance and soon became abundant (see pp. 695 & 697). Thereafter they suffered rapid decline and early extinction.

Mesozoic. Heavy glaciation, upheaval of mountains, redistribution of water and land areas in the late Palaeozoic brought about changes in the vegetation of the earth. Palaeozoic ferns and giant lycopods and horsetails disappeared and so also did most of the primitive gymnosperms. In the Mesozoic the primitive pteridophytes became replaced by newer herbaceous forms in large numbers, and the primitive gymnosperms replaced by Bennettitales (later extinct), Cycadales and Coniferales (both living and extinct), and Ginkgoales (now [illegible] of gymnosperms'.

Cenozoic. With the advent of the angiosperms and their rapid increase in number and widespread distribution in the Cretaceous, forming the dominant vegetation of the earth since then, the ferns and the gymnosperms have been thrown into the background. So Cenozoic is called the 'age of angiosperms'. Among the ancient angiosperms found in the Cretaceous and later mention may be made of water lilies and several arborescent types such as *Populus*, *Quercus*, *Ficus*, *Juglans*, *Magnolia*, *Fagus*, *Salix*, etc., and among monocotyledons several grasses, sedges, aroids, *Typha*, *Smilax*, palms, etc.

Pteridophytes

Psilopsida or *Psilophytinae*. Members of the Psilopsida are the most primitive vascular plants that were abundant and widespread during the Devonian period. There are 2 orders of Psilopsida: Psilophytales (altogether extinct) and Psilotales—a modern order with 2 genera, viz. *Psilotum* and *Tmesipteris*. The small plants of Psilophytales had a dichotomously branched stem with no leaves or very few small leaves in some. Roots were altogether absent. The underground portion of the stem (rhizome) bore numerous rhizoids in some genera. The xylem consisted of tracheids only. Reproduction was by spores of one type only (homosporous).

Order **Psilophytales**. Members of this order always bore sporangia at the tips of the branches. Today they are found in fossil form only,

but they had a world-wide distribution in the rocks of the Silurian and the Devonian. Our knowledge of this order began with the discovery of *Psilophyton* by Sir William Dawson in 1858. Other genera, viz. *Rhynia*, *Horneophyton* and *Asteroxylon*, were discovered by Kidston and Lang at Rhynie (Scotland) in 1917. These plants were commonly 30 to 60 cm. in height although some forms were larger, growing to a height of 2 to 3 m. Their tips showed circinate vernation very much like that of the ferns. The stele was a protostele, having a solid central core of xylem completely surrounded by a narrow zone of phloem. Gametophytes of these plants have never been found; nonetheless it is assumed that they possessed alternation of generations. Whatever might be the origin of these plants, they are generally believed to be the ancestors of lycopods, horsetails and ferns in divergent lines.

Lycopsida or *Lycopodinae*. Members of this class have the sporophyte differentiated into the root, stem and leaves, The leaves, mostly small, are regarded as evolutionary derivatives of the emergences of Psilopsida. The vascular system is commonly a protostele. [illegible]

[illegible] Lepidodendrales of this class is altogether extinct although other orders have living representatives.

Order **Lepidodendrales.** The plants of this order, known as giant lycopods, are represented by fossils only. They were tall trees having considerable secondary growth, and some of them reached a height of 40 m. and a diameter of 2 m. They had linear leaves, spirally arranged, which left characteristic leaf-scars on the stem on falling off. The stelar structure ranged from protostele to ectophloic siphonostele. They produced spores of two kinds (heterosporous): the microsporangium produced numerous small microspores, while the megasporangium produced 4 to 16 large megaspores. In some cases only a single megaspore matured. A female gametophyte was produced in the megaspore while still retained within the megasporangium, and after fertilization the entire structure was shed like the seed of a 'flowering' plant. They originated in the Devonian and reached their climax of development in the Carboniferous being the dominant plants of the coal age and hence important in the formation of coal. They disappeared by the end of the Palaeozoic. *Lepidodendron*, the best known genus, was much branched dichotomously towards the top of the stem and had leaves about 20 cm. in length.

Sphenopsida or *Equisetinae*. Members of this class also had sporophytes with distinct roots, stems and leaves. The stem was jointed and the leaves were small and simple, occurring in whorls at the nodes and forming a sort of sheath—a feature characteristic of this

group and distinguishing it from other pteridophytes. Another characteristic feature found among the Sphenopsida was the presence of sporangium-bearing axes (sporangiophores) in whorls. In many forms these sprongiophores were recurved so that the

Order **Sphenophyllales.** This order includes only the fossil genus *Sphenophyllum* which had grown and continued from the Devonian to the Triassic, being most abundant during the Carboniferous. The slender stem bore whorls of leaves at the nodes. The leaves were wedge-shaped and generally lobed, and each whorl consisted of 3 leaves or any multiple of this number. The sporophylls also occurred in whorls but in long cones or strobili. The plants were of small size.

Order **Calamitales.** This order represents the ancestry of living *Equisetum.* The principal genus is *Calamites,* the giant horsetail. *Calamites* was very abundant in the Carboniferous, though its life extended from the Devonian to the Triassic. The plants were very tall, some reaching a height of 20 to 30 m. They possessed cambium and showed considerable secondary growth, the stem often growing

Filicinae. The ferns constitute the largest class among the Pteridophyta, numbering about 7,800 species. They have a stem, well-developed leaves and roots. The sporangia are borne mostly on the leaves in groups or sori. Ferns were no doubt abundant in the Palaeozoic, but many of them later proved to be 'seed ferns' or Cycadofilicales. Some of the Palaeozoic ferns such as *Gleichenites, Schizaea, Marattia,* etc., have their living representatives today. With the close of the Palaeozoic the ferns declined and many of them disappeared altogether. In the Mesozoic new ferns appeared in diversified forms and soon become abundant and widespread. The descendants of many Mesozoic ferns have continued till today in increased numbers and forms. The order Coenopteridales of this class was extinct in the Palaeozoic.

Order **Coenopteridales.** The members of this ancient order occur only as fossils from the Devonian to the Permian. They were most

[*Continued on page 697*

Era	Period (age in million years)	Dominant Plants (& Animals)
CENOZOIC — QUATERNARY	Recent	Herbaceous plants dominate; forest trees decline. Civilization begins.
CENOZOIC — QUATERNARY	Pleistocene [1]	Many large trees die out, many hardy types of herbs *survive and increase. Great mammals die out.*
CENOZOIC — TERTIARY	Pliocene	Restricted distribution of forests; rise of herbs. Appearance of *man.*
CENOZOIC — TERTIARY	Miocene	Forest areas decrease; polar flora retreat; grasses increase Mammals reach zenith
CENOZOIC — TERTIARY	Oligocene	Tropical forests of angiosperms widespread. Primitive mammals disappear, higher mammals and birds increase.
CENOZOIC — TERTIARY	Eocene [60]	Pteridophytes continue; mesozoic gymnosperms disappear except cycads and conifers which decline, *angiosperms dominate; forests in polar regions.* Modern birds and higher mammals.
MESOZOIC	Cretaceous [125]	Pteridophytes continue, gymnosperms rapidly decline; angiosperms rapidly increase in a great variety of forms; modern forests begin; monocotyledons appear. Giant reptiles extinct; primitive mammals increase.
MESOZOIC	Jurassic [157]	[illegible] *of angiosperms* [illegible] primitive birds; higher insects.
MESOZOIC	Triassic [185]	[illegible] nosperms (cycads and conifers) increase. [illegible] mammals and giant reptiles (dinosaurs).
PALAEOZOIC	Permian [223]	Primitive pteridophytes and gymnosperms decline and almost disappear, *while advanced groups* (cycads conifers, etc.) appear. Land vertebrates.
PALAEOZOIC	Carboniferous [309]	Pterid[illegible] *mites* [illegible] primi[illegible] of ta[illegible] deposits. Amphibians increase, [illegible]
PALAEOZOIC	Devonian [354]	[illegible] *but soon* [illegible] ms: seed- [illegible] Origin of [illegible]
PALAEOZOIC	Silurian [381]	Marine algae dominant; origin of land plants; possible origin of Psilophytales. Higher invertebrates increase.
PALAEOZOIC	Ordovician [448]	Marine algae abundant. *Higher invertebrates.*
PALAEOZOIC	Cambrian [553]	Origin of marine algae Invertebrates; trilobites.
Proterozoic [1,500] & Archeozoic [2,000]		Simple thallophytes: bacteria and blue-green algae. *Unicellular and simple animals.*

For description see opposite page

Bennettitales. At the present time their number has dwindled to 100 species.

Order Cordaitales. The members of this extinct order of gymnosperms appeared in the late Devonian, reached their climax of development during the Carboniferous, and became extinct by the end of the Permian. They were not fern-like in their appearance like the Cycadophyta (Cycadofilicales, Bennettitales and Cycadales). On the other hand in their habit and in the structure of the secondary wood they approached the Coniferales, and are thus regarded as their ancestors. The Cordaitales were tall forest trees, often attaining a height of 30 m. They bore loose small unisexual strobili of two kinds —male and female—on the same plant. This order was contemporaneous with the Cycadofilicales, and it seems they had a common origin. *Cordaites* is the typical genus.

Order Ginkgoales. The members of this order were abundant and had world-wide distribution during the Mesozoic. Two important Mesozoic genera were *Baiera* and *Ginkgo*. Now the only living representative of the order is the maidenhair tree (*Ginkgo biloba*) which is referred to as the 'living fossil'. The order might have been derived from the Cordaitales.

Order Coniferales. The members of this order can be traced back to the Permian but they were abundant and widely distributed during the Mesozoic when they appeared in diversified forms, and reached their maximum development during the lower Cretaceous. They may have been derived from the Cordaitales. The order has continued up to the present day with living members numbering 500 species. As in the Mesozoic so also in the present period this is the largest order of the gymnosperms.

The Glossopteris Flora. The upper Carboniferous and the lower Permian of India, Australia, Africa and South America, called the Gondwanaland by the geologists, developed an entirely different flora from that of the North American and European areas. There is clear evidence of an extensive glaciation known as the Permo-Carboniferous Ice Age in this period. This heavy glaciation in the Southern Hemisphere killed most of the older vegetation. Succeeding this an almost entirely new type of vegetation appeared from the meagre flora that survived the catastrophe, and this is known as the *Glossopteris flora*. This is characterized by a small number of species and scarcity of woody plants. Fossils of leaves have been found, which have been named *Glossopteris*, and the flora as a whole the *Glossopteris* flora. The leaves are tongue-shaped, with reticulate venation and a fairly definite mid-rib. The plant probably belongs to the order Cycadofilicales. The *Glossopteris* flora is characteristic of the Lower Gondwana (Permo-Carboniferous) of the Gondwanaland continent. The Upper Gondwana (Mesozoic) on the contrary is predominated

by the *Ptilophyllum flora*, belonging to the order Bennettitales. In India the Gondwanaland stretches from the Godavari Valley to the Rajmahal Hills and is subdivided into a number of series and stages according to the respective fossil flora. During the Permo-Triassic transition the *Glossopteris* flora of the Lower Gondwana suffered a decline and a break, and was succeeded by the *Ptilophyllum* flora of the Upper Gondwana (Mesozoic). The *Glossopteris* flora is seen mainly in the coal beds of Talchir, Barakar and Raniganj areas, whereas the *Ptilophyllum* flora is characteristic of the Rajmahal and Jabalpur beds. The Gondwanaland began to break up during the Cretaceous, and in the Tertiary period angiospermic vegetation began to dominate, as we find in the present times.

Fossils of the Gondwana Rocks of India. Some of the *lower Gondwana* fossils are as follows. Lycopodiales—*Bothrodendron* Equisetales—*Schizoneura* and *Phyllotheca*; Sphenophyllales—*Sphenophyllum*; Pteridospermae—*Glossopteris* (several species), *Gangamopteris* and *Vertebraria*; Cordaitales—*Naeggerathiopsis* and *Dadoxylon*; Incertae (i.e., position uncertain)—*Samarapsis*, *Ottokaria* and *Cordaicarpus*. [illegible]

and *Brachyphyllum*.

Glossary of Names of Plants

Botanical name in *italics*; English name in Roman; Indian name in CAPITALS
A. for Assamese, B. for Bengali, G. for Gujarati, H. for Hindi, M. for Malayalam, M'. for Marathi, O. for Oriya, P. for Punjabi, T. for Tamil, and T'. for Telugu.

Abroma augusta—devil's cotton; A. BONKOPAHI; B. & H. ULATKAMBAL; G. GUMCHI; M'. OLAKTAMBOL; P. ULTKAMBAL, T. SIVAPPUTTUTTI

Abrus precatorius—crab's eye or Indian liquorice; A. LATUMMONI; B. KUNCH; H. & P. RATTI; M. KUNNI; M'. GUNJ; O KAINCHA, GUNJA; T. KUNDOOMONY; T'. GURUGINJA

Abutilon indicum—A. JAPAPETARI; B. PETARI; G. DABALI; H. KANGHI; M. & T. PERINTHOTTY; M' MUDRA; O PEDIPEDIKA; P. PILIBUTI; T'. THUTIRIBENDA

Acacia arabica—gum tree; A. TORUAKADAM; B. BABLA; G. KALOABAVAL; H. BABUL; M. & T. KARUVELAM; M'. BABHUL; O. BABURI; P. KIKAR; T'. NALLATUMMA

Acacia catechu—catechu; A., B. & M'. KHAIR; G. KHER; H. & P. KATHA, KHAIR; M. KADARAM; O. KHAIRA; T. KADIRAM, T'. KHADIRAMU

Acalypha indica—B. MUKTOJHURI; G VANCHI KANTO; H. KUPPI; M & T. KUPPAMANI; M'. KHOKALI; O INDRAMARISHA; P. KOKALI KUPPAMANI

Achras sapota—sapodilla plum; A. SAPHEDA; B. SHABEDA; H. & M. SAPOTA; M'. CHIKKU, O. SAPETA; P. CHIKU; T. SIMAIYILUPPAI, T'. SIMAIPPA

Achyranthes aspera—chaff-flower; A. UBTISATH; B. APANG; G. SAFED AGHEDO; H. LATJIRA, M. KATALADY; M'. AGHADA, O. APAMARANGA; P. PUTH KANDA, KUTRI; T. NAHIROORVY; T'. ATTARENI

Acorus calamus—sweet flag; A., B. & H. BOCH; G. GODAVAJ; M. VAYAMBU; M'. WEKHAND; O. BACHA; P. WARCH, BOJ, BARI; T. VASAMBOO; T'. VASA

H. ADALSA;
[illegible] SA SUBJ, BASUTI;

Aegle marmelos—wood-apple, A. & B BAEL; G. BILIVA-PHAL; H. SIRIPHAL; M. KOOVALAM; M'. BEL; O. BELA; P. BIL; T. VILVAMARAM; T'. BILAMBU

Aeschynomene indica—pith plant; A. KUNHILA; B, H. & P. SHOLA; M. KADESU ATTUKEDESU; O. SOLA; T. ATTUNETTEE; T'. JILUGA

Agave americana—American aloe or century plant; B. & H. KANTALA; G. JANGLI-KANVAR; M. NATTUKAITA; M'. GHAYPAT, O. BARABARASIA; P. WILAYATI KANTALA; T. ANAKUTTILAI, T'. BONTHARAKASI

Albizzia lebbek—siris tree; A., B., H, M'. & P. SIRISH; G. PITOSARSHIO; M. VAGA, O. SIRISA; T. VAGAI; T'. DIRISANA

Allium cepa—onion; A. PONORU; B., H. & P: PIYAZ; G. DUNGARI; M. ULLI; M'. KANDA; O. PIAJA; T. VENGAYAM; T'. YERRAGADDA

Allium sativum—garlic; A. NAHARU; B. RASUN; G. LASAN; H. & P. LASHUN; M. VELUTHULLI; M'. LASUN; O. RASUNA; T. VELLAIPOONDU; T'. TELLAGADDA

Alocasia indica—A. & B. MANKACHU; G. ALAVU; H. MANKANDA; M'. ALU; O. MANASARU; P. ARVI

Aloe vera—Indian aloe; A. CHALKUNWARI; B. GHRITAKUMARI; G. KUNVAR; H. GHIKAVAR; M. KATTARVAZHA; M'. KORPHAD; O. GHEEKUANRI; P. KAWARGANDAL, GHIKUAR; T. KUTTILAI

Alpinia allughas—A. TORA; B. TARA; M. CHITTARATHTHA; M'. TARAKA; O. GHODAGHASA; P. KALANJAN; T. PERIYARATHTHA

Alstonia scholaris—devil tree; A. CHATIAN; B. CHHATIM; H. CHATIUM, M. EZHILAMPALA; M'. SATVIN; O. CHHATIANA, CHHANCHANIA; P. SATONA; T. ELILAIPILLAI; T'. EDAKULAPALA

Alternanthera sessilis—B. SENCHI; G. JALAJAMBO; M. KOZHUPPA; M'. KANCHARI; O. MADARANGA; P. CHURA; T. PONNAN KANNI KEERAI; T'. PONAGANTIKURA

Amarantus spinosus—amaranth; A. KATAKHUTURA; B. KANTANATE; G. TANJALJO; H. & P. CHULAI; M. MULLANCHEERA; M'. KATE MATH, O. KANTANEUTIA, KANTAMARISHA; T. MULLUKKERAI; T'. MUNDLA THOTAKURA

Amorphophallus campanulatus—A. & B. OL; G. & M' SURAN; H. KANDA; M. CHAENA; O. OLUA; P. ZAMIN KANDA; T KARUNAKILANGU; T'. THIYA KANDHA

Anacardium occidentale—cashewnut; A. KAJUBADAM; B. HIJLIBADAM; G., H, M'. & P. KAJU; M. KASHUMAVU; O LANKA BADAM, T MUNDIRI, T'. JIDIMAMIDI

Andrographis paniculata—A. KALPATITA; B. & H. KALMEGH, MAHATITA; G. KIRYATO; M. KIRIYATHTHU; M'. PALEKIRAJET; O BHUINIMBA; P. CHARAITA; T. NELAVEMBU

Anisomeles indica—B. GOBRA; M. POOTHACHETAYAN, M'. GOPALI; O. BHUTA-AIRI; T. PEYAMERATTI

Annona reticulata—bullock's heart; A. ATLAS, B NONA, G., H, M'. & P. RAMPHAL; M. ATHA; O NEUA, BADHIALA, T. & T'. RAMSITA

Annona squamosa—custard-apple; A. ATLAS, B ATA, G & M'. SITAPHAL; H. & P. SHARIFA, SITAPHAL; M. SEEMA-ATHA; T. & T'. SEETHA

Areca catechu—areca- or betel-nut; A. TAMBUL; B, G., M'. & P. SUPARI; H. KASAILI; M. ADAKKA; O. GUA; T. PAKKU; T'. POKA

Argemone mexicana—prickly poppy; A. KUHUMKATA; B. SHEALKANTA; G. DARUDI; H. PILADHUTURA; M. SWARNAKSHEERI; M' PIWALA DHOTRA; O. AGARA; P. KANDIARI; T. BRAHMADANDU; T'. DATTURI

Aristolochia gigas—pelican flower; A., B. & O. HANSHALATA; M GARUDAKKODI; M'. POPAT VEL; P. BATKH PHUL; T. ADATHINAPALAI

Aristolochia indica—Indian birthwort; A. ISWERMUL; B. ISHERMUL; G. & M'. SAPSAN; H. ISHARMUL; M. ISVARAMMULI; O. GOPOKORONI; P. ANANTMUL, ISHARMUL; T. ADAGAM

G. & H. KANTALICHAMPA; CHINICHAMPA; P. CHAMPA;

Artocarpus integrifolia—jack tree; A. KOTHAL; B. KANTHAL; G. MANPHANASA; H. KATAHAR; M. & T. PILA; M'. PHANAS; O. PANASA; P. KATAR

Artocarpus lakoocha—monkey jack; A. CHAMA, DEWA; B. DEO, DEOPHAL; H. DEOPHAL, BARHAL; M'. LAKUCH; O. JEUTA; P. DEHEO

Asparagus racemosus—A. SHATMUL; B. SATAMULI; H. & P. SATAWAR; O. CHHATUARI; M., M'. & T. SATHAVARI; T'. SADAVARI

Azadirachta indica—margosa; A. MOHA-NIM; B., H. & P. NIM, NIMBA; G. LIMBA; M. VEPPU; M'. KADU LIMB; O. NIMBA; T. VEMBU; T'. VEPPAI

Baccaurea sapida—A. LETEKU; B. LATKAN; H. LUTKO; P. KALA BOGATI

Balanites sp.—A. HINGOOL; B. HINGAN; G. HINGER; H. & P. HINGOL, HINGU; M. NANJUNTA; M'. HINGANBET; O. HINGU; T. NANJUNDAN

Bambusa tulda—bamboo; A. BANH; B., H. & P. BANS; G. KAPURA; M. MULAH; M'. BAMBOO; O. BAUNSA; T. MULAI

Barringtonia acutangula—A. HIDOL; B. & H. HIJAL; G. SAMUDARPHAL; M. & T. SAMUNDRAKSHAM; M'. DHATRIPHAL; O. HINJALA; P. SAMUNDURAPHAL

Basella rubra—Indian spinach; A. PURAI, B. PUIN; H., O. & P. POI; M. SAMPARCHEERA, M'. VELBONDI; T. SAMBARKEERAI

Bassia latifolia—A., B. & H. MAHUA; G. MAHUDA; M'. MOHA; O. MAHULA; P. MOHWA; T. ILLUPPAI; T'. IPPA

Batatas edulis—sweet potato; A. & B. MITHA-ALOO; G. SHAKKARIA; H. & P. SHAKARKAND; M. MADHURAKI ZHANGU; M'. RATALA; O. CHINI-ALOO, KANDAMULA; T'. GENUSU

Bauhinia variegata—camel's foot tree; A., B. & M'. KANCHAN; G. KOVIDARA; H. & P. KACHNAR; M. MANDARUM; O. KANCHANA; T. TIRUVATTI; T'. ADAVIMANDARA

Benincasa cerifera—ash gourd; A. KOMORA; B. CHALKUMRA; G. KOHWLA; H. & P. PETHA; M. KUMPALAM; M'. KOHALA; O. PANIKAKHARU; T. KUMPALY; T'. PULLA GUMMUDI

Beta vulgaris—beet; A. BEET-PALENG; B. PALANG-SAK; G. & M'. BEET; H. & P. CHUKANDAR; O. PALANGA SAGA, BEET

Biophytum sensitivum—sensitive wood-sorrel; A. & B. BAN-NARANGA; G. JAHARERA; H. LAJALU, M. MUKKUTTI, THINDANAZHI; M'. LAJARI

Blumea lacera—A. KUKURSHUTA; B. KUKURSONGA; G. KALARA; H. & P. KOKRONDA; M'. BURANDO, O. POKASUNGA; T. KATUMULLANGI

Boerhaavia diffusa—A. PONONUA; B. & M'. PUNARNAVA; G. GHETULI; H. THIKRI, GADHAPURVA; M. THAZHUTHAMA; O. GHODAPURUNI; P. BISKHAPRA, ITSIT; T. MUKKARATAI; T'. PUNARNABA

Bombax malabaricum—silk cotton tree; A. SIMALU; B. SIMUL; G. RATOSHEMALO; H. & P. SIMAR, SIMBAL; M. & T' ELAVU, MULLILAVU; M'. KATE SAVAR; O. SIMULI, T'. KONDABURAGA, SALMALI

Borassus flabellifer—palmyra-palm; A. & B. TAL; G. & M'. TAD; H. & P. TAR; M. KARIMPANA; O. TALA; T. PANAI; T'. THADI

Boswellia serrata—incense tree; A. DHUNA; B. DHUP, GUGGUL; G. DHUP-GUGALI; H. GUGUL; M. MUKUNDAM; M'. DHUP; P. SALAI, SALER; T. ATTAM; T'. ANDUGA

Brassica campestris—mustard; A. SARIAH; B. SARISHA; G. SAFED-RAI; H. & P. SARSON; M. KATUKU; M'. MOHORI; O. SOROSHA; T. KARUPPUKKADUGU

Bryophyllum pinnatum—sprout-leaf plant; A. PATEGAZA, DUPORTENGA; B. PATHURKUCHI; H. ZAKHM-I-HAYAT; M'. PANPHUTI; O. AMARPOI; P. PATHURCHAT; T. RANAKALLI; T'. SIMAJAMUDU

Butea monosperma—flame of the forest or parrot tree; A., B. & M'. PALAS; G. KHAKARA; H. & P. DHAK; M. CHAMATHA; O. PALASA; T. SAMITHU, PALASAM; T'. MODUGA

Caesalpinia bonducella—fever nut; A. LETAGUTI; B. NATA; G. KAKACHIA; H. KATKARANJ; M. KAZHANCHIKKUROO; M'. SAGARGOTA; O. GILA; P. BEL KARANJWA; T. KALAKKODI

Caesalpinia pulcherrima—dwarf gold mohur or peacock flower; A. SWARNAKANTI; B. RADHACHURA; G. SANDHESHARO; H. GULETURA; M. RAJMALLI; M'. SHANKASUR; O. KRUSHNACHUDA, GODIBANA; P. KRISHANACHURA; T. MAYIRKONRAI; T'. TURAYI

Caesalpinia sappan—sappan or Brazil wood; B., H. & P. BAKAM; G. PATANG; M. PATRANGAM; M'. PATANG; T. PATANGAM; T'. PATANGA

Cajanus cajan—pigeon pea; A. RAHAR-MAH; B. ARAHAR; G. TUVARE; H. RAHAR; M. THUVARA; M'. TUR; O. HARADA; T. THOVARAY; T'. KANDULU

Calamus viminalis—cane; A. BAT; B., H. & P. BET; M. CHOORAL; M'. VET; O. BETA; T. SURAL

Calophyllum inophyllum—Alexandrian laurel; B & H. SULTANA-CHAMPA, PUNNAG; M. & P. PUNNA; M'. UNDI; O. POLANGA, T. PUNNAGAM; T'. PUNNAGA

Calotropis gigantea—madar; A. AKON, B AKANDA G AKADO; H & P. AK, M. & T. ERUKKU; M'. RUI; O. ARKA; T' JILLEDU

Canavalia gladiata—sword bean; A. KANTAL-URAHI, B MAKHAN-SHIM; H. BARA-SEM; M. & T. VAALAVARAKKAI; M'. ABAI, O BADA SIMBA, MAHARADA; P. BARASEM, TALWAR PHALI; T'. TUMBATTAN KAYA

Canna indica—Indian shot; A. PARIJAT-PHUL; B & O SARBAJAYA; G. KARDALI; H. SABBAJAYA; M. KATTUVAZHA; M'. KARDAL, P HAKIK, T KALVAALAI

Cannabis sativa—hemp; A. B., H. & P. BHANG, GANJA, G, P. & T GANJA, M. KANCHAVU; M'. BHANG; O. BHANGA, GANJI, T' GANJA CHETTU

Capsicum frutescens—chilli; A. JOLOKIA, B LANKA, MARICH, G LALMIRICHI; H. & P. LAL-MIRCH; M. MULAGU; M' MIRCHI, O LANKAMARICHA, T. MILAGU; T'. MIRAPAKAYA

Cardiospermum halicacabum—balloon vine, A. KOPALPHOTA, B KAPALPHUTKI, SHIBJHUL; G. KARODIO; M. VALLIYUZHINJA, M'. KAPALPHODI, O. PHUTPHUTKIA, P. HAB-UL-KULKUL; T. MODAKATHAN, T' BUDDAKAKKIRA, KASARITIGE

Carica papaya—papaw; A. AMITA; B. PAYPAY, G PAPAYI; H & P PAPITA; M. KARUTHA; M'. POPAI; O. AMRUTABHANDA; T PAPALI, T'. BOPPAYI

Carissa carandas—A. KORJA-TENGA; B. KARANJA, H. & P. KARONDA, M. ELIMULLU; M'. KARVANDA; O. KHIRAKOLI; T. KALAKKAI, T'. KALIVI

Carthamus tinctorius—safflower; A. & B KUSUMPHUL; G. KUSUMBO; H. & P. KUSAM; M. SINDOORAM; M'. KARDAI, O. KUSUMA; T. & T'. KUSUMBA

AJAMO, H & P AJOWAN;
OMAM; T' OMAMU

; B SHONDAL, G GARMALA;
H. & P. AMALTASH; M. & T. KONNAI; M'. BAHAWA, O. SUNARI

O. JHAUN; T. SAVUKKU; T'. SARAVU

Cedrela toona—toon; B., H. & P. TOON; M. CHUVANNAGIL; M'. MAHANIM; T. MALAVEMBU; T'. GALIMANU

Celosia cristata—cock's comb; A. KUKURA-JOA-PHUL; B. MORAG-PHUL; G. LAPADI; H. JATADHARI; M. KOZHIPULLU, M'. KOMBADA; O. GANJACHULIA; P. KUKUR-PHUL

Centella asiatica—Indian pennywort; A. MANIMUNI; B. THULKURI; G. KARBRAHMI; H. & P. BRAHMI-BOOTI, M KODANGAL, KOTAKAN, M'. BRAHMI; O. THALKUDI; T. VULLARAI

Cestrum nocturnum—queen of the night; A. & B. HAS-NA-HANA; H. RAT-KI-RANI

Chenopodium album—A. JILMIL-SAK; B. & H. BATHUA-SAK; G. CHEEL; M'. CHAKAVAT; O. BATHU SAGA, P. BATHU; T. PARUPUKKIRAI

Chrysanthemum coronarium—A. & B. CHANDRAMALLIKA; G & H. GULDAUDI; M. SHEVANTI; O. SEBATI; P. GULDAUD; T. SHAMANTIPPU; T'. CHAMANTI

Chrysopogon aciculatus—love thorn; A. BONGUTI; B. CHORKANTA; O. GUGUCHIA; P. CHORKANDA

Cicer arietenum—gram, A. BOOTMAH; B. CHHOLA; G., H. & P. CHANA; M. & T. KADALAI; M'. HARABHARA; O. BUTA; T'. SANIKALU

Cinnamomum camphora—camphor; A. & B. KARPUR; G., H. & M'. KAPUR; M. KARPPURAVRIKSHAM; O. KARPURA; P. KAFUR; T. KARUPPURAM; T'. KAPPURAMU

Cinnamomum tamala—bay leaf; A. TEJPAT, MAHPAT; B. TEZPATA; G. & H. TEZPAT; M'. TAMAL; O. & P. TEJPATRA; T. TALISHAPPATTIRI; T'. TALLISHAPATRI

Cinnamomum zeylanicum—cinnamon; A., B., G., M'., O. & P. DALCHINI; H. DARCHINI; M. & T. ILLAVANGAM; T'. LAVANGAMU

Cissus quadrangularis—A., B. & H. HARHJORA; M. PIRANTA; M'. KANDAWEL; O HADAVANGA; P. GIDAR-DAK, DRUKRI; T. PIRANDAI; T'. NALLERU

Citrullus colocynthis—colocynth; A. KOABHATURI; B. MAKAL; G. & H. INDRAYAN; M. & T. KUMMATHIKKAI, PEYKUMMATTY; M'. KAVANDAL; O. INDRAYANA; P. TUMMA; T'. PATSAKAYA

Citrullus vulgaris—water melon; A. KHORMUJA; B. TARMUZ; G. KARIGU; H. & P. TARBUZA; M. & T. KUMMATTIKKAI; M'. KALINGAD; O. TARABHUJA

Citrus aurantifolia—sour lime; A. NEMU-TENGA; B. KAGJI-NEBU; G. LIMBU; H. NIMBOO; M CHERUNARAKAM; M'. KAGADI LIMBU; O. LEMBU; P. GALGAL; T. ELIMICHCHAM; T'. NIMMAPANDU

Citrus reticulata—orange; A. KAMALA-TENGA; B. KAMALA; G. SUNTRA; H. NARANGI; M. NARAKAM; M'. SANTRA; O. KAMALA; P. SANGTRA; T. NARANGAM; T'. NARANJI

Citrus grandis—pummelo or shaddock; A. REBAB-TENGA; B. BATABI-NEBU; G. OBAKOTRU; H. & P. CHAKOTRA; M. BAMBLEENARAKAM; M'. PAPANAS; O BATAPI; T. BAMBALMAS

Cleome—see *Polanisia*

Clerodendron infortunatum—A. BHETTITA; B. & H. BHANT, GHENTU; M. PERU-VALLEM; G. & M'. KARI; O. KUNTI; P. KARU; T. KARUKANNI; T'. BASAVANAPADU

Clitoria ternatea—butterfly pea; A., B. & O. APARAJITA; G. GARANI; H. APARAJIT; M SANKHUPUSHPAM; M'. GOKARNA; P. APARAJIT, NILI LOEL; T. KAKKATAN, T'. SANGAPUSHPAM

Coccinia cordifolia—A. BELIPOKA; B. TELAKUCHA; H. BHIMBA; M. KOVEL; M'. TONDALE; O. KUNDURI, KAINCHIKAKUDI; P. GHOL; T. KOVARAI T'. KAKIDONDA

Cocos nucifera—coconut-palm; A. NARIKOL; B. NARIKEL; G., H. & P. NARIYAL; M. THENGU, NALIKERAM; M'. NARAL; O. NADIA; T. THENGU; T'. TENKAYA

Coix lachryma-jobi—job's tears; A. KAURMONI; B. & P. KALA-KUNCH, GURGAR; G. KASAI; H. SANKRU; M'. RAN JONDHALA, O. GARAGADA; T. KATTU KUNDUMANI

Colocasia esculenta—taro; A. & B. KACHU; H. & P. KACHALU; M. CHEMPU; M'. KASALU; O. SARU; T. SAMAKILANGOO; T'. CHEMA

Commelina bengalensis—A. KONASIMOLU; B. KANSHIRA; G. MHOTUNSHUSHMULIYUN; O. KANSIRI

Coriandrum sativum—coriander; A., B., H., O. & P. DHANIA; G. DHANE; M. & T. KOTTAMALLI; M'. KOTHIMBIR; T'. DHANIYALU

Crataeva religiosa—A. & B. BARUN; G. VAYAVARNA; H. & P. BARNA; M. NIRMATHALAM; M'. WAYAWARNA; O. BARUNA; T. MAVALINGAM; T'. VOOLEMERI

Crinum asiaticum—B & P. SUKHDARSHAN; M. POLATHALI; G. & M'. NAGDAUNA; O. ARISA; T. VESHAMOONGHEE

Crocus sativus—saffron; A., B. & O. JAFRAN; G. & M'. KESHAR; H. & P. ZAFRAN; T. KUNGUMAPU; T'. KUNKUMAPAVE

Crotalaria juncea—Indian hemp; A. SHON; B. SHONE; G., H. & P. SAN; M. THANTHALAKOTTI; M'. KHULKHULA; O. CHHANAPATA; T. SANAPPAI; T'. JANNAMU

Crotalaria sericea—rattlewort; A. GHANTAKORNA; B. ATASHI; H. JHUNJHUNIA; M. THANTHALAKOTTI; M'. GHAGRI; O. JUNKA; P. JHANJHANIAN

Croton tiglium—A. JOYPAL; B. JAIPAL; G JAMAL GOET; H., M'. & P. JAMALGOTA; M. & T. NIRVALEM; O. BAKSA GACHHA

Cucumis melo—melon; A. BANGI; B. PHUTI; G. TARBUCH, H. & P. KHARBUZA, PHUTI & KAKRI; M. & T. THANNIMATHAI; M'. KHARBUJ; O. KHARBUJA

Cucumis sativus —cucumber; A. TIANH, B. SASHA; G KAKRI; H., M'. & P. KHIRA; M. MULLENVELLARI; O. KAKUDI; T. MULLUVELLARI

Cucurbita moschata—sweet gourd; A. RONGALAU; B. MITHAKUMRA, H. MITHA-KADDU; M. MATHANGAI; M' KALA BHOPALA; O. MITHA KOKHARU; P. HALWA-KADDU; T. POOSANIKAI

Curcuma amada—mango ginger; A. & B. AMADA, G AMBA-HALDAR; H. AM-HALDI; M'. AMBE HALAD; O. AMBA KASSIA ADA, P. AMBA HALDI; T'. MAMIDIALLAM

Curcuma domestica—turmeric, A. HOLODHI, B. HALOOD; G. & M'. HALAD; H. & P. HALDI; M. KUVA; O. HALADI; T. MANJAL, T'. PASUPU

Cuscuta reflexa—dodder; A. AKASHILOTA, RAVANARNARI; B. SWARNALATA; G. AKASWEL; H. AKASHBEL; M'. AMAR VEL, O. NIRMULI, P. AMARBEL

Cynodon dactylon—dog grass; A. DUBORIBON, B. DURBAGHAS; G. DURVA; H. & P. DOOB; M. & T. ARUGAMPULLU, M'. HARALI; O. DUBA GHASA; T'. GERICHA GADDI

Cyperus rotundus—sedge; A. MOTHA; B. & H MUTHA; G. BARIK-MOTHA; M. KORA; M'. & P. NAGAR-MOTHA; O. MUTHA GHASA; T. KORAI; T'. PURA GADDI

Dalbergia latifolia—Indian rosewood; B. SITSAL; G. SISAM; M. & T. ITTI; M'. SISSU; O. PAHADI SISU; T'. JITTEGI

Dalbergia sissoo—Indian redwood; A. SHISHOO; B. SISSOO; G. SHISHAM; H. & P. SHISHAM, TAHLI; M. VEETI; M' SHISAVI; O SISU

Datura fastuosa—thorn-apple; A. DHOTURA; B. DHUTRA; G. DHATOORA; H. & P. DHUTURA; M. UMMAM, M'. DHOTRA; O. DUDURA; T. OOMMATHAI; T'. UMMATHA

Delonix regia—gold mohur; A. & B. KRISHNACHURA; G., H., M'. & P. GULMOHR; M. MARAMANDARAM; O. RADHACHUDA; T. MAYILKONNAI

Desmodium gangeticum—B. SALPANI; G. SALVAN; H. SALPAN; M. PULLATI; M'. SALPARNI; O. KURSOPANI; P. SHALPURHI; T. PULLADI; T'. GITANARAM

Desmodium gyrans—Indian telegraph plant; A. & B. BANCHANDAL, GORACHAND; H. BAN-CHAL; O. GORA CHANDA, TELEGRAPH GACHHA; P. PAUDA TAR

Dillenia indica—A. OU-TENGA; B., H. & P. CHALTA; G. CARAMBAL; M. VALLAPUNNA; M'. KARAMAL; O. OU; T, UVATTEKU; T'. UVVA

Dioscorea alata—white yam; A. KATH-ALOO, PATNI-ALOO; B. & H. CHUPRI-ALOO, KHAM-ALOO; M'. KONA; O. KHAMBO-ALOO; P. KNISS; T. KAYAVALLI; T'. GUNAPENDALAMU

Dioscorea bulbifera—wild yam; A. GOCH-ALOO; B. GACHH-ALOO; G. SAURIYA; H. & P. ZAMINKHAND; M. KATTUKACHIL; M'. KADU KARANDA; O. DESHI-ALOO, PITA-ALOO; T. KATTUKKILANGU; T'. CHEDUPADDUDUMPA

Diospyros ebenum—Indian ebony; B. ABLOOSH; H. TENDU; M. KARU: M'. & P. ABNUS; T. KAKKAYTTALI; T'. NALLAVALLUDU

Diospyros embryopteris—wild mangosteen; A. & O. KENDU; B. & P. GAB; G. TEMRU; H. TENDU; M. VANANJI; M'. TEMBURNI; T. TUVARAI; T'. TUMMIKA

Dolichos lablab—country bean; A. UROHI; B. SHIM; G. AVRI; H. & P. SEM; M. SIMA-PAYARU; M'. PAVATA; O. SIMA; T. AVARAI; T'. CHIKKUDI

Duranta plumieri—A. JEORA-GOCH; B. DURANTA-KANTA; H. & P. NILKANTA; M'. DURANTA; O. BILATI KANTA, BENJUATI

Ecbolium linneanum—B. NILKANTHA; H. & P. UDAJATI; M. KURANTA; M'. RAN ABOLI; O. NILAKANTHA; T. NILAMBARI

Eclipta alba—A. KEHORAJI; B KESARAJ; G. BHANGRA; H. & P. SAFED BHANGRA; M. & T. KAYYANYAM, KAITHONNI; M'. MAKA; O. KESHDURA

Elephantopus scaber—elephant's foot; B. & H. HASTIPADA, GOBHI; G. BHOPA THARI; M. & T. ANACHUVADI; M'. HASTI PAD; O. GOBI; P. GAOZBAN

Eleusine coracana—B. & H. MARUA; G. NAVTO; M. PANJAPPULLU; M'. NACHANI; O. MANDIA; P. KODRA, MANDWA; T. KOLVARAKU; T'. RAGI

Enhydra fluctuans—A. HELACHI-SAK, MONOA-SAK; B. & P. HALENCHA; H. HARUCH; M'. HARKUCH; O. HIDIMICHI, PANI SAGA

Entada scandens—nicker bean; A. GHILA, B., H., O & P. GILA; G. SUVALI-AMLI; M. KAKKUVALLY; M'. GARBI; T. CHILLU; T'. GILLATIGAI

Enterolobium saman—rain tree; A. SIRISH GOCH; M. URAKKAM-THOONGIMARAM; M'. SAMAN; O. BADA GACHHA CHAKUNDA, BANA SIRISHA

Ervatamia divaricata—A. KOTHONAPHUL; B. & M'. TAGAR; H. & P. CHANDNI; M. & T. NANTHIAR VATTAM; O. TAGARA

Erythrina indica—coral tree; A. MODAR; B. MANDAR; G. PANARAWAS; H PANJIRA; M. & T. MURUKKU; M'. PANGARA; O. PALDHUA; P. DARAKHT FARID, PANGRA

Euphorbia antiquorum—B. BAJBARAN or TESHIRA-MANSHA; G. TANDHARI; M. CHATHIRAKKALLI; M'. CHAUDHARI NIWDUNG; O. DOKANA SIJU; P. DANDA THOR, TIDHARA SEHUD; T. SHADRAIKALLI; T'. BONTHAKALI

Euphorbia nerifolia—A. SIJU; B. MANSHASIJ; G. THOR; H. SIJ; M. & T. ILAKKALLI; M'. CHAUDHARI NIWDUNG; O PATARA SIJU; P. GANGICHU; T'. AKUJEMUDU

Euphorbia nivulia—A SIJU, B. SIJ; G. THOR KANTALO; H SIJ, THOR; M. & T. ILAKKALLI; M'. NIWDUNG; O. SIJU; T'. AKUJEMUDU

Euphorbia pulcherrima—poinsettia; A LALPAT; B., M'. & P. LALPATA; O. PANCHUTIA; P. LAL-PATTI; T. MAYILKUNNI

Euryale ferox—A. NIKORI; B , H. & P. MAKHNA; M'. PADMA KANT, MAKHAN; O. KANTA PADMA

Evolvulus alsinoides—G. JHINKIPHUDARDI; H. SHYAMAKRANTA; M. VISHNUKTANTHI, KRISHNAKTANTHI; M'. VISHNU KRANT; O. BICHHAMALIA; P SHANKH-HOLI; T VISHNUKIRANDI; T'. VISHNUKRANTHI

Feronia—see *Limonia*

Ferula asafoetida—asafoetida; A., B., G., H., M'. & P. HING; M KAYAM; O. HENGU

Ficus bengalensis—banyan; A BORGOCH; B. BOT; H & P. BARH; G. & M'. WAD; M. PEERALU; O. BARA; T. AALUMARAM; T'. MARRI

Ficus glomerata—fig; A DIMORU; B. DUMUR; G. UMBARO; H. & P. GULAR; M. & T. ATHTHYMARAM; M'. UMBAR; O DIMURI; T'. BODDA

Ficus religiosa—peepul; A. ANHOT; B. ASWATTHA; G. JARI; H & P. PIPAL; M ARAYALU; M' PIMPAL; O. ASWATHA, T. ARASU, T'. ASWATHAM

Flacourtia cataphracta—A PONIAL; B & H. PANIALA; G. TALISPATRA; M. & T. TALISAM; M'. JUGGUM; O. PANIONLA; P. PANIALA, PANIAUNLA; T'. TALISAPATRAMU

Flacourtia ramontchi—B. BOINCHI; H BOWCHI, BILANGRA; M'. BHEKAL; O. BAINCHA KOLI; P. KATAI, KUKAI; T. MALUKKARAI; T'. KANARIGU

Foeniculum vulgare—anise or fennel; A. GUAMOORI; B PANMOURI, G. WARIARI; H. & P. SAUNF; M'. BADISHEP; O. PAN MOHURI

Garcinia mangostana—mangosteen; B., H & M'. MANGUSTAN; G MANGOSTEEN; M. SULAMPULI; O. MANGOSTEEN, SITAMBU; T. SULAMBULI

Gardenia florida—cape jasmine; A. TOGOR; B., H. & P. GANDHARAJ; G. DIKAMALI; M'. GANDHRAJ; O. SUGANDHARAJ

Girardinia zeylanica—A. SHORUCHORAT; B BICHUTI; M AANACHORIYANAM; O. BICHHUATI; P. BICHUTI, BHABHER

Gloriosa superba—glory lily; A. & B. ULATCHANDAL; G. & M'. KHADYANAG; H. KALIARI, KULHARI; M. MANTHONNI, PARAYANPOOVA; O. PANCHAANGULIA; P. GURHPATNI, KULHARI; T, KALAPAI-KILANGU, T'. AGNISIKA

Glycosmis arborea—A. CHAULDHOA; B ASHHOURA; H BANNIMBU; M. PANAL; O. CHAULADHUA

Gossypium herbaceum—cotton; A. KOPAH; B., H & P KAPAS; G. RUI; M. KURUPARATHY; M'. KAPUS; O. KAPA, T PARATHY

Gynandropsis gynandra—A. BHUTMULA, B HURHURE; G ADIYA-KHARAM; H. HURHUR; M. KATTUKATUKU; M' TILVAN, O ANASORISIA, SADA HURHURIA; P. HUL-HUL; T. NAIKADUGU; T'. VAMINTA

Helianthus annuus—sunflower, A. BELIPHUL, B & O. SURJYAMUKHI, G. SURYAMUKHI; H. & P. SURAJMUKHI, M., T & T' SURIYAKANTI; M'. SURYAPHUL

Heliotropium indicum—heliotrope; A. & B. HATISUR, G. HATHISUNDHANA; H. HATTASURA; M. TEKKADA; M'. BHURUNDI, O. HATISUNDA; P UNTH-CHARA

Hemidesmus indicus—Indian sarsaparilla; A. & B ANANTAMUL; G. DURIVEL; H. SALSA; M'. ANANTMUL; O. ANANTAMULA, KAPRI; P. DESI SARVA; T. NANNARI; T'. SUGANDIPALA

Hibiscus cannabinus—Madras or Deccan hemp, B. NALITA; G BHINDI; H. AMBARI; M. KANJARU; M'. AMBADI; O. KAUNRIA, NALITA, P. SAN-KUKRA; T. KACHURAI

Hibiscus esculentus—lady's finger; A., O & M'. BHENDI; B., H. & P. BHINDI; G. BHINDA; M. & T. VENDAKKA; T'. BENDA

Hibiscus mutabilis—A. & B. STHALPADMA; G UPALASARI, H. GULIAJAIB; M. CHINAPPARATTI; M'. GULABI BHENDI, O. THALAPADMA; P. GUL-I-AJAIB, T. SEMBARATTAI

Hibiscus rosa-sinensis—China rose or shoe-flower; A JOBA; B. JABA; G. JASUNT; H. GURHAL, JASUM; M. CHEMPARATHY, M' JASWAND; O. MANDARA; P. GURHAL, JIA PUSHPA; T. SAMBATHOOCHEDI; T'. DASANI

Hibiscus sabdariffa—rozelle; A. MESEKA-TENGA; B. MESTA; H. & P. PATWA; M. PULICHI; M'. LAL-AMBADI; O KHATA KAUNRIA

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Holarrhena antidysenterica—A. DUDKHORI; B KURCHI; G. INDRAJAVANU; H KARCHI; M. KODAKAPPALA; M'. KUDA; O. PITA KORUA; P. INDER JAU, KAWAR

Hordeum vulgare—barley; A. & B. JOB; G. BAJRI; H. JAWA; M'. SATU; O. BARLEY, JABA; P. JAU; T. BARLIYARISI; T' YAVAKA

Hydrocotyle—see *Centella*

Hygrophila spinosa—B. KULEKHARA; G. EKHARO; H. GOKULA-KANTA; M'. KOLSHINDA; O. KANTAKALIA, KOILIKHIA, P. TALMAKHANA; T. NIRMULLI

Impatiens balsamina—balsam; A. DAMDEUKA; B DOPATI; H. GULMENDI; M. & T. BALSAM; M'. TERADA; O. HARAGOURA; P. MAJITI, BANTIL, PALLU

Indigofera tinctoria—indigo; A., B., H. & P. NIL; G. GALI; M. AMARY; M'. NEEL; O NILA; T. AVARY; T'. AVIRI

Ipomoea reptans—water bindweed; A. KALMAU; B. & H. KALMI-SAK; G. NALINIBHAJI; M'. KALAMBI, NAL; O. KALAMA SAGA; P. NALI, KALMI SAG

Ipomoea pes-tigridis—B. LANGULI-LATA; M. VELLATAMPU; O. KANSARINATA; P. ISHOPECHAN

Ixora coccinea—A. & B. RANGAN; H. GOTAGANDHAL; M. & T. CHETHTHY, THETTY; M'. MAKADI; O. KHADIKA PHULA, RANGANI; P. RUNGAN

Jasminum sambac—jasmine; A. JUTIPHUL; B & H. BELA; G. BATMOGRI; M. MULLA; M'. MOGARA; O. MALLI

Jatropha curcas—physic or purging nut; A. BONGALI-ARA; B. BAGH-BHARENDA; G. JEPAL; H. JANGLI-ARANDI; M. KATALAVANAKKU; M'. MOGALI ERAND; O. BAIGABA; P. JAMALGOTA, JABLOTA, JAPHROTA

Jatropha gossypifolia—A. BHOTERA, B., H. & P. LAL-BHARENDA; M'. VILAYATI ERAND; O. NALI BAIGABA, VERENDA; T. ADALAI; T'. NEPALEMU

Jussiaea repens—A. TALJURIA; B. KESSRA, M. NIRGRAMPU; M'. PAN LAWANG; T. NIRKIRAMPU; T'. NIRUYAGNIVENDRAMU

Lagenaria siceraria—bottle gourd; A. JATI-LAU; B. & O. LAU; H. LAUKI; M. & T. CHORAKKAI; M'. DUDHIYA BHOPALA; P. GHIYA

Lagerstroemia flos-reginae—A. AJAR; B., H. & P. JARUL; M. NIRVENTEKKU; M'. TAMAN; O. PATOLI; T. PUMARUTHU

Lantana aculeata (=*L. camara*)—lantana; G. GHANIDALIA; M. PUCHEDI; M'. GHANERI; O. NAGA-AIRI; P. DESI LANTANA; T. ARIPPU; T'. LANTANA

Laportea crenulata—devil or fever nettle; A. DOM-CHORAT; M. CHORIYANAM; M'. & P. CHORPATTA, T'. OTTAPILAVU

Lathyrus aphaca—wild pea; A. & B. BAN-MATAR; G. JANGLI VATANA; H. JANGLI-MATAR; M'. VANMATAR; O. JANGALI MATAR; P. JANGLI MATAR, RAWARI

Lathyrus sativus—A. KOLA-MAH; B., H. & O. KHESARI; G. MATER; M'. LAKH; P. KISARI DAL

Lemna paucicostata—duckweed; A. SORUPUNI; B. KHUDI-PANA; M'. TIKLICHE SHEWALE; O. CHUNIDALA; BILATI DALA; P. BUR

Lens culinaris—lentil; A. MOSOORMAH; B. MASURI; G. MASURIDAL; H., M'. & P. MASUR; O. MASURA

Leonurus sibiricus—A. RONGA-DORON; B. DRONA; H. HALKUSHA, GUMA; O. BHUTA-AIRI, KOILIKHIA

Lepidium sativum—garden cress; A. & B. HALIM-SAK; G. ASALIYA; H. HALIM; M'. ALIV; O. HIDAMBA SAGA; P. HALON

Leucas linifolia—A. DORON, DURUM-PHUL; B. SWET-DRONA; G. JHINA-PANNI KUBO; H. CHOTA-HALKUSA; M. THUMPA; M'. DRONAPUSHPI, GUMA; O. GAISA; P. GULDODA, T. THUMBAI; T'. TAMMA CHETTU

Limonia acidissima—elephant-apple; A. & B. KATH-BAEL; G. KOTHA; H. & P. KAITHA; M. BLANKA; M'. KAWATH; O. KAINTHA; T. VELAMARUM; T'. VELANGA

Linum usitatissimum—linseed; A. TICHI; B. TISHI, G. JAVA; H. & P. ALSHI; M'. JAWAS; O. PESI; T. AALIVIRAI

Loranthus longiflorus—A. ROGHUMALA; B. MANDA; G. VANDO; H. BANDA; M. ITHTHIL; M'. BANDGUL; O. MALANGA, MADANGA; P. PAND; T. PULLURUVI; T'. BAJINNIKI, BADANIKA

Luffa acutangula—ribbed gourd; A. JIKA; B. JHINGA; G. SIROLA; H. & P. *KALITORI; M. PEECHIL, PEECHINGAI; M'. DODAKA; O. JAHNI;* T. PEECHANKA

Luffa cylindrica—bath sponge or loofah; A. BHOL; B. DHUNDUL; H. & P. GHIYA-TORI; M'. GHOSALE; O. PITA TARADA

Lycopersicum esculentum—tomato; A. BELAHI-BENGENA; B. BILATI-BEGOON; H. & P. TAMATAR; G. TAMETA, TOMATO, RAKTAVURNITANK; M. & T. THAKKALIKKAI; M'. TAMBETA; O. BILATI BAIGANA; T'. *THAKKALI*

Malva verticillata—mallow; A. & B. LAFFA; H. & P. SONCHAL

Marsilea quadrifida—A. PANI-TENGECHI; B. SUSHNI-SAK; M. NALILAKKOTAKAN; O. SUNSUNIA; P. CHAUPATI; T. ARAKKODAI

Martynia diandra—tiger's nail; A. & B. BAGHNAKHI; G. VICHCHIDA; H. SHERNUI; M. & T. KAKKACHUNDU, PULINAGAM; M'. WINCHAURI; O. BAGHA NAKHI; P. HATHAJORI; T'. GARUDA MUKKU

Mentha arvensis—mint; A. PODINA; B., G., H. & M'. PUDINA; M. *PUTIYINA*

Mesua ferrea—iron-wood; A NAHOR; B. NAGESWAR; H. NAGKESAR; M. & T. IRUMPARATHTHAN; M'. NAGCHAMPAKA, O. NAGESWARA, P. NAGAR KESAR; T'. NAGAKESARI

Michelia champaca—A. & P. CHAMPA-PHUL; B CHAMPA or SWARNACHAMPA; G. RAE CHAMPAC; H. CHAMPAK; M. & T CHEMPAKAM; M' SONCHAPHA; O. CHAMPA; T'. SAMPAKA

Millingtonia hortensis—Indian cork tree, B , H , M & P AKASNIM; O. RIALI

Mimosa pudica—sensitive plant, A LAJUKILOTA; B LAJJABATILATA; G. LAJJAWANTI; H. & P. LAJWANTI; M. THOTTALVADI; M' LAJALU; O. LAJAKULI, LAJKURI; T. THOTTASINIGI, T' PEDDA NIDRAKANTHA

Mirabilis jalapa—four o'clock plant or marvel of Peru; A GODHULIGOPAL; B. KRISHNAKOLI; H GULABBAS, M. NALUMANICHEDI; M' GULBAKSH; O. RANGANI, BADHULI, P. GUL-E-ABBASI, T. ANDIMANDARAI; T'. CHANDRAKANTA

Momordica charantia—bitter gourd; A TITA-KERALA; B. KARALA, UCHCHE; G., H. & P. KARELA; M & T. PAVAL, PAVAKKAI, M'. KARLE, O KALARA; T'. KAKARA

Moringa oleifera—drumstick or horse radish; A. & O. SAJANA; B SAJINA; G. SARAGAVA; H. SAINJNA; M. MURINGA, M'. SHEVAGA, P. SAONJNA; T. MURUNGAI; T'. MUNAGA

Morus indica—mulberry; A NOONI; B. TOONT; G. TUTRI; H. & P SHAH-TOOT; M. MALBERRY; M'. TUTI; O. TUTAKOLI

Mucuna pruriens—cowage; A. BANDARKEKOA; B. ALKUSHI; G KIVANCH; H. & P. KAWANCH; M. NAIKORUNA; M'. KHAJ KUIRA; O. BAIDANKA

Murraya exotica—chinese box; A. KAMINIPHUL, B & O. KAMINI; H. MARCHULA; M. MARAMULLA; M'. PANDHARI KUNTI; P. MARUA; T. KATTUKARUVEPPILAI; T'. NAGAGOLUGI

Musa paradisiaca—banana; A. KOL; B. KALA; G. & H KELA; M. VAZHA; M'. KADALI, KEL; O. KODOLI, ROMBHA; T. VAZHAI; T'. ARATI, KADALI

Myristica fragrans—nutmeg; B., H , M'. & P. JAIPHAL; G. JAYIPHAL; M. & T. JATHIKKAI, O. JAIPHOLO, T'. JAJIKAYA

Nelumbium speciosum—lotus, A PODUM; B. & O. PADMA; G & M'. KAMAL; H. & P. KANWAL; M. THAMARA; T. THAMARAI; T'. DAMARA

Nerium odorum—oleander; A. KORBIPHUL; B KARAVI, G. & M'. KANHER; H. & P. KANER; M. & T. ARALY; O. KARABI; T'. GANNERU

Nicotiana tabacum—tobacco; A. DHOPAT; B. TAMAK, G., H., M'. & P. TAMBAKU; M. & T. PUKAYILA; O. DHUANPATRA; T'. POGAKU

Nigella sativa—black cumin; B. & O. KALA-JIRA; G. KADU-JEEROO; H. KALOUNJI; M. & T. KARUN-JIRAGAM; M'. KALA JIRE; P. KALONGI, KALA-JIRA

Nyctanthes arbor-tristis—night jasmine; A. SEWALI; B. SHEWLI, SHEPHALI; G. RATRANE; H. HARSHINGAR; M. PAVIZHAMULLA; M'. PARIJATAK; O. SINGADAHARA; P. HARSANGHAR; T. PAVELAM; T'. PARIJATHAM

Nymphaea lotus—water lily; A. BHET; B. SHALOOK; G. NILOPAL; H. & P. NILOFAR; M. & T. AMPAL; M'. LALKAMAL; O. KAIN, KUMUDA

Ocimum sanctum—sacred basil; A. TULASHI; B , G., H. & P. TULSI; M. & T. THULASI; M'. TULAS; O. TULASI; T'. ODDHI

Oldenlandia corymbosa—B. & P. KHETPAPRA; G. PARPAT; H. DAMANPAPPAR; M'. PITPAPADA; O. GHARPODIA

Opuntia dillenii—prickly pear; A. SAGORPHENA; B. PHANIMANSHA; G. NAG-NEVAL; H. NAGPHANI; M. ELAKKALLI; M'. PHADYA NIWDUNG; O. NAGAPHENI; P. CHITARTHOR; T. SAPPATHTHIKKALLI; T'. NAGADALI

Orobanche indica—broomrape; B. BANIABAU; H. & P. SARSON-BANDA; T. POKAYILAI-KALAN

Oroxylon indicum—A. BHATGHILA; B. SONA; G. PODVAL; H. ARLU; M. PATHIRI; M'. TETU; O. PHANPHANIA, PHAPANI; P. SANNA; T. PAYYALANTHA; T'. PAMPINI

Oryza sativa—paddy; A., B. & H. DHAN; G. CHOKHA; M. ARI; M'. BHAT; O. DHANA; P. CHAWAL; T. ARISHI; T'. URLU

Oxalis repens—wood-sorrel; A. SENGAITENGA, TENGECHI; B. AMRULSAK; H. CHUKATRIPATI, KHATTIPATTI; M. PULIYARILA; M'. AMBOSHI; O. AMBILITI, AMLITI; P. KHATTIBUTI

Paederia foetida—A. BHEDAILOTA; B GANDHAL; G. GANDHANA; H. GANDHALI; M TALANILI; M'. PRASARUM; O. PASARUNI; P. GUNDALI; T'. SAVIRELA

Pandanus odoratissimus—screw-pine, A. KETEKI, B. & G. KETAKY; H. & P. KEORA; M KAITHA; M'. KEWADA; O. KIA, T. THAZHAI; T'. MOGIL

Panicum miliaceum—Indian millet; B. H., O. & P. CHEENA; G. SAMLI; M. THENA; M'. WARAI; T VARAGU; T'. VARAGI

Papaver somniferum—opium poppy; A, AFUGOCH; B AFING, G. APHIM; H. & P. POST, M. & T. KASHAKASHA, M'. APHU; O. APHIMA

Passiflora foetida—passion-flower, A. JUNUKA; B., H & P. JHUMKALATA; M KRISTHUPAZHAM; M'. KRISHNA KAMAL, O. JHUMUKA-LATA; T SIRUPPUNAIKKALI; T'. TELLAJUMIKI

Pedilanthus tithymaloides—jew's slipper; B RANGCHITA; H. NAGDAMAN, M. VERAKKODI, M'. VILAYATI SHER; O BILATI-SIJU, CHITA-SIJU; P. NAG DAUN

Pennisetum typhoides—pearl millet; B., H., O & P. BAJRA; M. & T. KAMPU, BAJRA; M'. BAJARI; T'. SAJJA

Pentapetes phoenicea—noon flower; B. DUPOHRIA; G. DUPORIO, H & P. GULDUPAHARIA; M'. DUPARI, O. DIPAHARIA

Phaseolus aureus—green gram, A. MOGU-MAH; B & H. MOONG; G MUGA; M CHERUPAYARU, M'. HIRAVE MUG; O JHAIN-MUGA; P. MUNG; T. PACHAPAYARU; T'. PESALU

Phaseolus mungo—black gram; A. MATI-MAH; B. MASH, KALAI, G. UDAD; H URID; UZHUNNU; M'. UDID; O. MUGA; P. MASH; T. ULUNNU, T'. UDDULU

Phoenix sylvestris—date-palm, A. & B KHEJUR; G, H. & P. KHAJUR; M. ITTA; M'. KHARIK; O. KHAJURI, T. ICHCHAM; T' ITHA

Phragmites karka—A. KHAGRA, B & P NAL; H. NUDA-NAR; O. JANKAI

Phyllanthus acidus—A. HOLPHOLI, PORAMLOKHI; B NOAR; H CHALMERI, HARFARAURI; M NELLIPULI, ARINELLI; M'. RAY AWALI; O. NARAKOLI; T ARUNELLI, T'. RATSAVUSIRIKI

Phyllanthus emblica—emblic myrobalan; A. AMLOKI, B AMLA, AMLAKI, G. AMBALA; H. AMLIKA; M. & T. NELLIKKAI; M' AWALA; O. ANLA; P. AMLA; T'. USIRI

Piper betle—betel, A, B., G., H. & P. PAN; M. & T. VETHILA; M'. NAGWELI; O. PANA; T'. TAMALAPAKU

Piper cubeba—cubeb; B., H. & O. KABAB-CHINI; G. TADAMIRI; M, & T. THIPPLI; M'. KABAB CHINI, KANKOL; T' TOKAMIRIYALU

Piper longum—long pepper; A. PIPOLI; B PIPOOL; G. PIPARA; H. PIPLI; M. THIPPALI; M'. PIMPALI; O. PIPALI; P. DARFILFIL, MAGHAN

Piper nigrum—black pepper; A. JALUK; B. GOLMARICH; G. KALOMIRICH; H. GOLMIRCH, M. KURUMULAGU; M'. KALI MIRI; O. GOLA MARICHA; P. KALI MARCH; T. MILAGOO; T'. SAVYAMU

Pistia stratiotes—water lettuce; A. BORPUNI; B. PANA, G. JALAKUMBHI; H. & P. JALKHUMBI; M. MUTTAPPAYAL; M'. GANGAVATI; O. BORA JHANJI; T. AGASATHAMARAI; T'. AKASATAMARA

Pisum sativum—pea; A. MOTOR; B., H, O. & P MATAR; G. VATANA; M. PAYARU; M'. WATANE; T. PATTANI; T'. GUNDUSANIGHELU

Plantago ovata—A., B. & O ISOBGUL; G. UTHAMUJEERUM; H, M'. & P. ISOBGOL; M. KARKATASRINGI; T'. ISHAPPUKOL

Plumbago zeylanica—A. AGYACHIT; B. CHITA; G. CHITRAMULA; H., M'. & P. CHITRAK; M. & T. KODUVELI; O. DHALACHITA

Plumeria rubra—pagoda tree; A. GULANCHI, B KATGOLAP; G RHAD-CHAMPO; H. & P. GOLAINCHI; M. EEZHAVA-CHEMPAKAM; M' KHUR CHAPHA; O. KATHA CHAMPA; P. GULCHIN

Polanisia icosandra—B. HALDE-HURHURE; G. TILVAN; H. HULHUL, M. & T. NAIKADUGU; M'. PIWALI TILVAN, O. ANASORISIA, P. BUGRA, GANDHULI; T'. KUKKA VAVINTA

Polyalthia longifolia—mast tree; A. & O DABADARU, B DEBDARU; G. ASHOPALO; H. & M'. ASHOK; M. ARANAMARAM; P. DEVIDARI, T NETTILINGAM

Polyanthes tuberosa—tuberose; A,, B & O. RAJANIGANDHA, H & P. GULSHABO; M'. GULCHHADI; T. NILASAMPANGI; T'. SUKANDARAJI

Polygonum sp.—A. BIHLONGONI; B. PANI-MARICH, M MOTHALA-MOOKA; O. MUTHI SAGA; P. NARRI; T. AATALARIE

Pothos scandens—A. HATILOTA; G MOTO PIPAR; M. ANAPPARUVA, M'. ANJAN VEL; O. GAJA PIPALI; P. GAZPIPAL

Prosopis spicigera—A. SOMIDH; B., H, M'. & O SHOMI, G KANDO; M PARAMPU; P. JAND; T. PERUMBAI; T'. JAMBI

Psidium guayava—guava; A. MODHURI-AM; B. PAYARA, G JAMFAL; H. & P. AMRUD; M. PERAKKA; M' PERU, O PIJULI; T. KOYYA; T'. JAMA

Pterospermum acerifolium—A. KONOKCHAMPA; B MOOCHKANDA; H. KANAK-CHAMPA; M'. MUCH KUND; O MOOCHKUNDA, T VENNANGU

Punica granatum—pomegranate; A. & B DALIM; G. DADAM; H. & P. ANAR; M. MATALAM; M'. DALIMB; O. DALIMBA, T. MADULAM

Quamoclit pinnata—A. KUNJALOTA; B. KUNJALATA, TORULATA; H. & P. KAMLATA; M'. GANESH PUSHPA; O. KUNJALATA

.TI;

Raphanus sativus—radish; A, B, M'. & O. MULA; H. & P. MULI; M. MULLANKI; T. & T'. MULLANGI

Rauwolfia serpentina—A. CHANDO; B, G. & T. SARPAGANDHA; H., M'. & P. SARPGANDH; M. AMALPORIYAN; O. PATALA GARUDA

Ricinus communis—castor; A. ERIGOCH; B. & P. ARANDA; G. ERANDI; H. RENDI; M. & T. AVANAKKU; M'. ERAND; O. JADA; P. RENDI, ARANDA; T'. AMIDAMU

Rumex vesicarius—sorrel; A. CHUKA-SAK; B. CHUKA-PALANG; H. KHATTA-PALAK; M'. CHUKA; O. PALANGA; P. KHATTA-MITHA

Saccharum officinarum—sugarcane; A. KUNHIAR; B. & H. AKH; G. SHERDE; M. & T. KARIMPU; M'. USA; O. AKHU; P. GUNNA; T'. CHERUKU

Saccharum spontaneum—A. KANHBON; B. KASH; G. & H. KANS; M. NAINKANA; M'. BAGBERI; O. KASHATANDI; P. KAHI

Sansevieria roxburghiana—bowstring hemp; A. GUMUNI; B. MURGA, MURVA; H. MARUL; M. PAMPINPOLA; O, MURUGA; T. MARUL

Santalum album—sandalwood; A., B., H., M'. & P. CHANDAN; G. SUKHADA; M. & T. CHANNANAMARAM; O. CHANDANA; T'. CHANDANAMU

Sapindus mukorossi & S. trifoliata—soap-nut; A. MONICHAL, HAITAGUTI; B., H, M'. & P. RITHA; G. ARITHA; M. URVANJI; O RITHA, MUKTAMANJI; T. PONNANKOTTAI; T'. KUNKUDU

Saraca indica—A, B. & P. ASOK; G. ASUPALA; H. SEETA-ASOK; M. & T. ASOKAM; M'. SITECHA ASHOK; O. ASOKA

Sesamum indicum—gingelly; A. TISI; B., H., M'. & P. TIL; G. MITHO-TEL; M. & T. ELLU, O. KHASA, RASHI; T'. NUVVULU

Sesbania grandiflora—A. & B. BAKPHUL; G. AGATHIO; H. & P. AGAST; M. AGATHI; M'. AGASTA; O. AGASTI; T. AGATHYKKEERAI; T'. AVISI

Sesbania sesban—A. JOYANTI; B. JAINTI; G. RAYSANGANI; H & P. JAINT; M. SHEMPA; M'. SEVARI; O. JAYANTI; T. SITHAGATHI

Setaria italica—Italian millet; A. KONIDHAN; B. KAUN; G KANG, H. CHEENA, KAUNI; M. NAVANA; M'. RALE; O. TANGUN; P, KANGNI; T. TENNAI; T'. KORRA, KORALU

Shorea robusta—A , B., H. & P. SAL; G. RAL; M. MARAMARAM; M'. SHALA, RALVRIKSHA; O. SALA; T. SHALAM

Sida cordifolia—A BARIALA; B. BERELA; G. JANGLI-METHI; H. BARIARA; M. KURUMTHOTTI; M'. CHIKANA; O. BISIRIPI; P. KHARENTI; T. KARUMTHOTTEE; T'. CHIRUBENDA

Smilax macrophylla—sarsaparilla; A. HASTIKARNA-LOTA; B. KUMARIKA; H. CHOBCHINI; M'. GHOT VEL; O. KUMBHATUA, KUMARIKA, P. USHBA

Solanum ferox—A BON-BENGENA; B. RAM-BEGOON; M. ANACHCHUNTA; M'. BHAJICHE WANGE; O BHEJI BAIGANA; T. ANAICHUNDAI; T'. MULAKA

Solanum indicum—A. BHEKURI-GOCH, TIT-BHEKURI; B. BRIHATI; G. UBHIRINGANI; H. BIRHATTA, M. KATTUCHUNDA, M' DORLI; O. KANTARA; P. BARI KANDIARI

Solanum melongena—brinjal; A BENGENA, B. BEGOON; G. & O. BAIGANA; H BAIGON; M. VAZHUTHANA; M'. WANGE, P BENGAN; T. KATHTHIRI; T'. VANGA

Solanum nigrum—black nightshade, A POKMOU; B. GURKI; G. PILUDU; H GURKAMAI; M. MULAGUTHAKKALI; M'. KANGANI, O NUNNUNIA; P. MAKO; T. MANATHAKKALI, T'. KAMANCHICHETTU

Solanum tuberosum—potato; A , B , H , O. & P. ALOO; G. PAPETA; M. & T. URULAKKIZHANGU; M'. BATATA; T' URULAGADDA

Solanum xanthocarpum—A. KANTAKARI, B. KANTIKARI; G. BHOYARINGANI; H KATELI, KATITA; M. KANDAKARYCHUNDA; M'. KATERINGANI; O ANKARANTI; P. KANDIALI; T. KANDANKATHTHIRI; T'. NELAVAKUDU

Sorghum vulgare—great millet; A. JOUDHAN; B. & G. JUAR, H. & P. JOWAR; M. & T. CHOLAM; M'. JAWAR; O. BAJARA

Sterculia foetida—A BAN-BADAM; B , H , M'. & P JANGLI-BADAM; G. NARKYA-UDA; M ANATHTHONDI, O. JANGALI BADAM; T. PAEMARAM; T'. GUTTAPUBADAMU

Syzygium aromaticum—clove; A., H. & P. LAUNG, B. LAVANGA; G. LAVANG; M. GRAAMPU; M'. LAWANG; O LABANGA

Syzygium cumini—A. JAMU; B. KALA-JAM, G. JAMDUDO; H. & P. JAMAN; M. & T. NAAVAL; M', JAMBUL; O JAMUKOLI

Syzygium jambos—rose apple; A. GOLAPI-JAMU; B. GOLAP-JAM; H. & P. GULAB-JAMAN; M. PANINIRCHAMPA; M'. GULAB JAMB; O. GOLAP JAMU; T. NAAVAL; T'. NEERIDU

Syzygium malaccense—malay apple; A. PANI-JAMU; B. JAMRUL; H MALAY-JAMAN; M'. SAFED JAMB, P. MALAY KA SEB

Tabernaemontana—see *Ervatamia*

Tagetes patula—marigold; A NARJIPHUL; B. & H. GENDA; M'. GULJAPHIRI; O. GENDU; P GENDA, GUTTA

Tamarindus indica—tamarind; A. TETELI; B TENTUL; G AMIL; H. & P. IMBLI; M. & T PULI; M'. CHINCH; O. KAINYA, TENTULI; T'. CHINTHA

•*Tamarix dioica*—A. JHAU-BON; B. & H. BON-JHAU; M'. JAO; O. DISHI-JHAUN-THARTHARI; P. PILCHI

Tectona grandis—teak; A. & B. SHEGOON; G. & H. SHAGWAN; M. & T. THEKKU; M'. SAG; O. SAGUAN; P. SAGWAN; T'. TEKU

Tephrosia purpurea—wild indigo; A. BON-NIL; B. & H. JANGLI-NIL; G. JHILA; M. KOZHINGIL; M'. SHARAPUNKHA; O. BANA NILA; P. JHANA; T. KOLINGI; T'. VEMPALI

Terminalia arjuna—A. ARJUN-GOCH; B. & H. ARJUN, G. SAJADAN, M. VELLI-LAVU; M'. ARJUN-SADADA; O. ARJUNA; P. ARJAN; T. MARUTHU; T' TELLA MADOI

Terminalia belerica—beleric myrobalan; A. BHOMRA-GUTI, B. & P BAHERA; G. BERANG; H. BHAIRAH; M. & T. THANNIKKAI, M' BEHADA, O BAHADA

Terminalia catappa—country almond—A. BADAM-GOCH; B., G., H., M'., O. & P. DESHI-BADAM, M ADAMARAM; T. NATTUVADUMAI; T'. BADAMI

Terminalia chebula—chebulic myrobalan; A. SHILIKHA; B. HARITAKI; G. PILO-HARDE; H. & P. HARARA; M. & T. KADUKKAI, M', HIRDA, O. HARIDA; T'. KARAKA

Thespesia populnea—portia tree; B. PARAS; G PURUSA-PIPALO, H. & P. PARAS-PIPAL; M. & T. POOVARASU; M' BHENDICHA JHAR; O. HABALI; T'. GANGARAVI

Thevetia peruviana—yellow oleander; A. KARABI; B KALKE-PHUL, G., H. & P. PILA-KANER; M. & T. SIVANARALI; M'. PIWALA KANHER; O. KANIARA, KONYAR PHULA; T'. PACHCHAGANPERU

Tinospora cordifolia—A. AMORLOTA, AMOILOTA; B GULANCHA; G. GADO; H. GURCHA; M. AMRITHU; M'. GULVEL; O. GULUCHI, P GALO; T. SINDHILKODI; T'. TIPPATIGE

Tragia involucrata—nettle; A. CHORAT; B. BICHUTI; H & P. BARHANTA; M. CHORIYANAM; M'. KHAJAKOLTI; O. BICHHUATI; T. KANJURI; T'. DULAGONDI

Trapa bispinosa—water chestnut; A. SHINGORI, B PANI-PHAL; G SHENGODA; H. & P. SINGARHA; M. KARIMPOLA; M'. & O SINGADA; T SINGARAKOTTAI; T'. KUBYAKAM

Trewia nudiflora—A. BHELKORA; B. PITULI, H. BHILLAURA; M. THAVALA; M'. PITARI; O. JANDAKHAI, PANIGAMBHAR; P. TUMARI, KHAMARA; T. AATTARASU

Tribulus terrestris—B. GOKHRIKANTA; G. GOKHARU, H. GOKHRU; M. NERUNJIL; M'. KATE GOKHRU; O. GOKHARA; P. BHAKHRA; T. NERINJI; T'. PALLERU

Trichosanthes anguina—snake gourd; A. DHUNDULI; B. CHICHINGA; G. PADAVALI; H. CHACHINDA; M. PADAVALAM; M'. PADVAL; O. CHHACHINDRA; P. PAROL; T. PUDALAI; T'. POTLA

Trichosanthes dioica—A. & B. PATAL; H. & P. PARWAL; M. PATOLAM; G. & M'. PARWAR; O. PATALA; T. KOMBUPPUDALAI; T'. KOMMUPOTLA

Trigonella foenum-graecum—A. MITHIGUTI; B, G, H., O, M'. & P. METHI; M. VENTHIAM; T. VENDAYAM

Triticum sativum—wheat; A. GHENHU; B. GOM; G. GAHUN; H. & P. GEHUN; M. KOTHAMPU; M'. GAHU; O. GAHAMA; T. GHODUMAI; T'. GOTHI, GODUMULU

Typha elephantina—bulrush or elephant grass; B. HOGLA; G. GHABAJARIN; H. PATER; M'. PAN KANIS; O. HAUDAGHASA, HOGOLA; P. PATIRA; T. CHAMBU

Typhonium trilobatum—A. SAMAKACHU; B. GHETKACHU; M. CHENA; T. KARUNKARUNAI, ANAIKKORAI; T'. JAMMUGADDI

Urena lobata—A. BON-AGARA; B. BAN-OKRA; H. & P. BACHATA; M. OORPUM; M'. VAN-BHENDI; O. JATJATIA; T. OTTATTI

Utricularia sp.—B. JHANJI; M. MULLANPAYAL, KALAKKANNAN; M'. GELYACHI VANASPATI; O. BHATUDIA DALA

Vanda roxburghii—orchid; A. KOPOUPHUL; B., H. & P. RASNA; G. RASNA-NAI; M. MARAVAZHA; M'. BANDE; O. RASHNA, MADANGA

Vangueria spinosa—A. KOTKORA, MOYENTENGA; B. MOYENA; H. MOINA; M'. ALU; O. GURBELI; T. MANAKKARAI; T'. SEGAGADDA

IDEVI, KUKSHIM;

Vigna sinensis—cow pea; A. NESERA-MAH; B. BARBATI; H. BORA; M'. CHAVLI; O. BARGADA; P. RAUNG; T. THATTAPAYERU; T'. ALACHANDALU

Vinca rosea—periwinkle; A. & B. NAYANTARA; H. SADABAHAR; M. KASITHUMPA; M'. SADAPHULI; O. SADABIHARI; P. RATTAN JOT

Viscum monoicum—mistletoe; A. ROGHUMALA; B. BANDA; H. & P. BHANGRA-BANDA; M. ITHTHIL; M'. JALUNDAR; O. MALANGA; T. OTTU

Vitis trifolia—B. AMAL-LATA; G. KHAT-KHATUMBO; H. & P. AMALBEL; M. SORIVALLI; M'. AMBATVEL; O. AMARLATA

Vitis vinifera—grape vine; A., B., H. & P. ANGOOR; G. MUDRAKA; M. & T. MUNTHIRYVALLY; M'. DRAKSHA-VEL, O. ANGURA; T'. DRAKSHA

Wedelia calendulacea—A. BHIMRAJ; B. BHIMRAJ, BHRINGARAJ; G., H. & P. BHANGRA; M. PEE-KAYYANNYAM; M'. PIVALA-BHANGRA; O. BHRUNGA-RAJA

Withania somnifera—A. LAKHANA; B. ASWAGANDHA; G. ASUNDHA; H. & P. ASGANDH, M. & T. AMUKKIRAM; M'. ASKANDH; O. AJAGANDHA; T'. ASVAGANDHI

Wrightia tomentosa—A. DUDHKHOROI; B. INDRAJOB; G., H. & P. DUDHI; M. & T. NILAM-PALA; M'. KALA-INDERJAW; O. PHAOKURNI; T'. PALA

Xanthium strumarium—cockle-bur; A. AGARA; B. & H. OKRA; G. GADIYAN; M'. SHANKESHVAR; O. CHOTA GOGHURU; P. GOKHRU KALAN; T. MARLUMUTTA; T'. MARULAMATHANGI

Xanthophyllum budrunga—A. BROIONALI; B. BAZINALI; H. BADRANG; M. KATTUMURIKKU; M'. BUDRANJ; T. IRATCHAI; T'. RACHAMAM

Zea mays—Indian corn or maize; A. MAKOI-JOHA; B. BHUTTA; G., H. & P. MAKAI; M. & T. CHOLAM; M'. & O. MAKA; T'. MOHKA-JONNA

Zingiber officinale—ginger; A., B. & O. ADA; G. ADHU; H. ADRAK; M. INCHI; M' ALE; P. ADARAK; T. INJI; T'. ALLAM

Zizyphus jujuba—Indian plum; A. BAGARI; B. KUL; G. BORADI; H. & P. BER; M. & T. ELANTHAI; M'. BOR; O. BARKOLI; T'. REGU

Zizyphus oenoplia—A. BAN-BAGARI; B. SHIAKUL; M. THODALI; M'. BURGI; O. BHUINKOLI; P. MAKOH; T. SOORAI; T'. BANKA

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